INVESTIGATING AGE-RELATED DIFFERENCES IN SPATIAL PRESENCE FORMATION AND MAINTENANCE IN VIRTUAL REALITY

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Sean A. McGlynn

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INVESTIGATING AGE-RELATED DIFFERENCES IN SPATIAL PRESENCE FORMATION AND MAINTENANCE IN VIRTUAL REALITY

Approved By:

Dr. Wendy A. Rogers, Advisor
College of Applied Health Sciences
University of Illinois Urbana-Champaign

Dr. Bruce N. Walker, Chair
School of Psychology
Georgia Institute of Technology

Dr. Maribeth G. Coleman
School of Interactive Computing
Georgia Institute of Technology

Dr. Scott D. Moffat
School of Psychology
Georgia Institute of Technology

Dr. Eric H. Schumacher
School of Psychology
Georgia Institute of Technology

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SUMMARY

The harmony of sensory information across the different modalities is what helps provide people with a sense of where they are and what they can do in a given place. Certain technologies have advanced to the point that they are capable of simulating this accumulation of multi-modal information; creating the sensation of being physically located and the able to physically act within a digital environment. Virtual reality (VR) is one such technology, and it has applications that have the potential to maintain and enhance physical, cognitive, and socio-emotional well-being for users of varying characteristics and abilities. These applications span across diverse domains such as education, entertainment, healthcare, manufacturing, meditation and mental health, the military, physical therapy and activity, and even space exploration.

Although virtual reality has the potential to simulate the sensation of being physically located in a virtual environment, whether it reaches this potential is wholly dependent on how the human user reacts to the VR system and if they accept the virtual environment as the one in which they are located. If the user accepts the virtual environment as their primary egocentric reference frame, they are said to be experiencing spatial presence in the virtual environment.

Spatial presence is a psychological experience, during which perceived self-location and perceived action possibilities are connected to a virtual spatial environment, and mental capacities are bound by the virtual environment instead of reality. Crucially, the extent that the desired outcomes of VR applications are achieved often depends on the extent that the VR user experiences spatial presence in the virtual

environment. When VR has been used for applications such as training, therapy, and other interventions, there is evidence that higher spatial presence can lead to more enjoyment, more effective collaborations, higher treatment efficacy, higher transfer of training, and better adherence to exercise interventions. However, these findings are somewhat mixed due partly to disagreements on the concept of spatial presence and its measurement, as well as disagreements on the minimum technological capacity of the system (its 'immersiveness') required to elicit the sensation of presence. As a result, the literature on spatial presence is difficult to parse and compare across studies that refer to presence, but define and measure it in different ways using systems that differ greatly in their ability to simulate sensory information realistically.

In addition to these limitations, the study of presence has focused almost solely on levels of presence. Although most models of presence acknowledge that presence is a process, the most common methods of measuring presence (post-experience questionnaires) are not sensitive to other components of the process such as presence formation, presence maintenance, and recovery from breaks in presence. Additionally, it is unclear how these components of the presence process might change over time or with experience (which is relevant to long-term VR applications). Furthermore, spatial presence is a human sensation, yet, it is unclear how human factors impact the likelihood and extent that people will experience this sensation in the virtual environment. The samples in the vast majority of studies on presence are limited in the range of potentially presence-relevant abilities such as perception and cognition and the types of perceptual and cognitive abilities that influence presence are often underspecified.

This dissertation addressed these limitations in the following ways. A highly immersive VR system was used as a way to increase the likelihood that presence was experienced. The system was held constant so the role of human factors could be investigated. Multiple methods of presence measurement were used and/or administered that were sensitive to presence formation, level, maintenance, and recovery. Age was used as a proxy for changes in presence-relevant abilities. Specific hypothesized presence-relevant abilities were measured.

The following research questions were addressed to empirically test a theoretically grounded model of the spatial presence process:

1. How long does it take for presence formation to occur?
2. To what extent do people experience presence?
3. How well do people maintain presence?
4. How well do people recover when breaks in presence occur?
5. How well do existing and novel methods capture the presence process?
6. Are differences in presence accounted for by individual differences in certain cognitive and perceptual abilities?

For questions 1-5, and additional aim was to understand if there were age-related differences in the components of the presence process and in the validity of measurement of these components.

25 younger and 25 older adults participated in a three-day research study. The essential qualities of each of the study days were a passive VR session, an active VR training session, an active VR criterion test session, and an active VR experimental session. Post-experience presence questionnaires were administered following the

passive VR session and the active VR experimental session. Additionally, Days 2 and 3 of the study included measures of presence that were sensitive to temporal fluctuations in the presence process; a break in presence counter and a retrospective presence slider. A semi-structured interview regarding participants experiences of presence was administered at the end of Day 3. Additionally, ability assessments were administered at the beginning of each of the study days.

In general, there was limited evidence suggesting that differences in the components of the spatial presence were due to age or due to individual differences in cognitive abilities. Overall, presence formation occurred very quickly. Levels of presence were high and remained high over the course of the study. Younger adults did experience more breaks in presence, but in general, people maintained a sense of presence in the virtual environment for the majority of time spent in VR. When breaks in presence occurred, people were able to easily recover, such that they quickly regained their sense of presence in the virtual environment. These findings were consistent across the multiple methods of assessing presence, providing evidence of convergent validity for temporally-sensitive presence measures. Although there were caveats to some of the presence measures, the caveats appeared to affect both age groups equally.

These findings led to insights and recommendations that contribute to the theory of the spatial presence process and have practical applications for researchers, interventionists, and designers of VR systems. The key contributions of this dissertation are as follows:

- Insights on presence formation, maintenance, and break recovery in addition to levels of presence using a multi-method approach
- Improved understanding of the presence process across a diverse range of users
- Understanding of potential changes in presence as a result of time and VR experience
- Validation of temporally-sensitive presence measurement methods
- Insights and recommendations for researchers, interventionists, and VR designers

VR continues to be applied to new settings. If advanced technologies are to be used to help maintain and enhance various physical, cognitive, and socio-emotional aspects of life, it is necessary to consider if VR is an appropriate tool for these settings and if so, why? By advancing our theoretical understanding of the entire spatial presence process and providing practical insights regarding the use of virtual reality systems, this dissertation is informative for maximizing the effectiveness of VR as tool across various domains and user-types.

CHAPTER 1: INTRODUCTION

Virtual reality (VR) is an emerging technology with the potential to benefit physical, cognitive, and socio-emotional well-being for users of all ages across various domains. VR has applications in the contexts of training (Satava, 1995); education (Wickens, 1992); healthcare and wellness (Chirico et al., 2016; Jungjin Kim, Son, Ko, & Yoon, 2013; Satava, 1995); the military (Baumann, 1993); communication (Biocca, 1992), manufacturing (Gavish et al., 2015), and entertainment (Bates, 1992). For VR applications to be effective, the user must experience a sense of being physically located in the digital environment. This subjective experience is referred to as spatial presence (or just "presence") and is considered to be the primary goal of virtual reality. Thus, understanding the factors involved in this experience is critical for maximizing the benefits of VR applications.

Much of the research on spatial presence in VR has focused on the impact of immersiveness, which is the system's objective properties (e.g., screen resolution, field of view), on spatial presence. Yet, spatial presence is a psychological state of the user and as such, is subject to individual differences even if the VR system is held constant. Indeed, a recent meta-analyses found only a moderate effect of immersiveness on presence (Cummings & Bailenson, 2016). Technology advances at an exponential rate (Kurzweil, 2004). As the computational capacity of VR systems continues to rapidly improve, such that simulating sensory stimuli becomes increasingly feasible, variation in spatial presence will likely be more dependent on the characteristics and abilities of the VR *users* than on the qualities of the VR itself.

Although most theories of spatial presence acknowledge that user characteristics play a role, few studies have empirically tested person variables specifically. Factors such as attentional and perceptual abilities are purported as being critical in the spatial presence process (Draper, Kaber, & Usher, 1998). That is, for presence to occur, the stimuli projected by the system must be perceived and attended to by the user. Psychology has long specified key distinctions between different types of attention, but these distinctions have not yet been incorporated into theories of presence. Additionally, the participants for most studies of presence have been college undergraduates, who tend to be relatively high in most attentional abilities. If VR is to be used by a range of people across a wide variety of domains, it is necessary to expand the study of presence to more diverse users. Furthermore, measurement of spatial presence in VR is limited to overall levels of the sensation. Spatial presence is an ongoing process, the study of which should also include how presence is formed and maintained as well as how people respond when presence is broken. This raises the challenge of how to measure presence within-experience such that temporal fluctuations can be captured.

In prior work, I developed a conceptual model of spatial presence to synthesize previous empirical research and proposed a framework within which testable hypotheses could be generated (McGlynn & Rogers, under review). Emphasis was on extending previous models to incorporate individual differences and the mechanisms through which they might drive presence formation and maintenance. The goal of this dissertation was to test components of this model empirically while addressing limitations in the extant spatial presence literature.

The Concept of Spatial Presence

The human sensory system continuously gathers information about the surrounding environment throughout life. Spatial presence occurs when the synthesis of this information across sensory modalities results in a cohesive representation of the environment, one's embodiment within the environment, and the potential for action possibilities in the environment. In most circumstances, people accumulate consistent evidence suggesting that they are currently physically present in the physical environment. That is, they have a coherent spatial mental model of their current surroundings. Stimuli can be incongruent with this spatial mental model without resulting in a conclusion that presence resides elsewhere, however, if these 'incongruent' stimuli begin to converge continuously across modalities, it may provide evidence of one's location in an alternate space. If this evidence is sufficiently convincing, one's subjective physical location may differ from one's objective physical location.

Although spatial presence typically resides in the physical environment, it is a not a particularly useful concept in the VR context. One *feels* present in the physical environment because she/he *is* present in the physical environment. The value in considering physical presence in spatial presence research, however, is to identify the psychological processes that occur in physical environments (e.g., attention) that are likely to be relevant to spatial presence and to treat physical presence as the "gold standard" by which to compare technology-mediated experiences to (Lessiter, Freeman, Keogh, & Davidoff, 2001).

Spatial Presence in Virtual Reality

Advanced technologies such as VR have the capacity to induce spatial presence in a non-physical environment (Seibert, 2014). Specifically, spatial presence is a hybrid binary/continuous experience, during which perceived self-location, and, in most cases, perceived action possibilities are connected to a mediated spatial environment, and mental capacities are bound by the mediated environment instead of reality (McGlynn & Rogers, in prep; Wirth et al., 2007). Although previous research has included low-immersive media such as books and television as "mediated environments", interactions with these types of media are not likely elicit true spatial presence, which *can* be achieved using immersive VR. Virtual reality has been defined as a real or simulated environment in which a perceiver experiences [tele]presence (Steuer, 1992). Combining this with the definition of spatial presence, I define a virtual reality system as one that enables one to perceive self-location and action possibilities within a technology-mediated environment.

Eliciting presence is the central goal of VR because there is evidence that in many virtual applications, the outcomes are dependent on or improved when presence is experienced (Slater & Wilbur, 1997). Individuals who experienced greater presence in an exposure therapy intervention experienced more emotional reactions, which were critical for treatment efficacy (Hodges et al., 1995). Therapies are also more easily accepted if presence is experienced (Stanney, Mourant, & Kennedy, 2006). Presence was positively correlated with enjoyment of a virtual museum tour (Sylaiou, Mania, Karoulis, & White, 2010). Digital content was more persuasive for people who experienced presence (Kim & Biocca, 1997). Depending on the requirements of the task, feeling present can lead to better performance (Bystrom, Barfield, & Hendrix, 1999; Stanney & Salvendy, 1998). Finally, increasing the sense of presence experienced is thought to lead to higher quality training outcomes (Wallis & Tichon, 2013; Witmer & Singer, 1998).

Though these linkages between presence and outcomes highlight opportunities for potential applications of VR, the findings are mixed and require further evidence using systematic approaches (Lombard & Ditton, 1997; Schuemie, Van Der Straaten, Krijn, & Van Der Mast, 2001). Studies sometimes use non-immersive systems (Vorderer et al., 2004) or do not explicitly measure presence, instead assuming (erroneously) that increasing the immersiveness of the system will *necessarily* increase presence. This can lead to a conclusion that presence had no effect on the desired outcomes when it may actually be the case that there were individual differences in the effect that increasing immersiveness had on presence, thereby nullifying potentially significant results.

These limitations emphasize the necessity to distinguish the concepts of immersiveness and presence to better understand how person factors influence presence. Spatial presence refers to the psychological state of the user, whereas the objective qualities of the system have been termed immersion (Slater & Wilbur, 1997). However, the term used should reflect that this is a technology-driven concept. The system is not immersion, the system is *immersive* and different systems vary on a spectrum of immersiveness (McGlynn & Rogers, in prep). These terms will be used to mean what Slater and Wilbur (1997) referred to as immersion. Thus, immersiveness is the extent to which the illusion of reality that the technology is capable of delivering is inclusive (i.e., excludes physical stimuli), extensive (i.e., breadth of sensory modalities stimulated), surrounding (i.e., degree of panoramic displays), and vivid (i.e., resolution of the displays). Of note is that these four aspects of immersiveness are not mutually exclusive. For example, all else being equal, adding an additional sensory modality (e.g., sound) to make the system more extensive will almost always increase the inclusiveness (because ambient noise from the environment is no longer as easily perceived). Indeed, a greater sense of presence can generally be expected as the immersiveness of the system increases; however, a recent meta-analysis found only a medium effect of immersiveness on presence (Cummings & Bailenson, 2016).

There are several potential explanations for the moderate effect of immersiveness on presence. First, the concept of spatial presence itself is not well-agreed upon, nor is the minimum level of immersiveness required to elicit presence. As a result, some studies have compared different levels of immersiveness but using only technologies that may not have the capacity to elicit presence (e.g., high vs. standard definition on 2D screen). Though these findings are useful in certain contexts, they are not directly relevant to the theory of spatial presence in VR more generally.

Conceptual issues also lead to disagreements in the methods used to measure spatial presence. Post-experience self-report questionnaires are the most common measurement method for spatial presence (Schuemie et al., 2001; Witmer & Singer, 1998). There are clear advantages to using questionnaires; they have obvious face validity, several of them are theory-driven and have been validated through factor analyses, they are sensitive to different levels of immersiveness, and can be diagnostic if they acknowledge the multidimensionality of presence (Hartmann et al., 2015).

However, some of the more frequently used questionnaires cannot distinguish between the experience of spatial presence and participants' assessments of the technology's immersiveness (Slater, 1999; Witmer & Singer, 1998) because they include questions about the technology itself. Another concern is that the concept of spatial presence may not be well-understood by participants, and as a result, the experience of spatial presence may be misreported (Slater et al., 1995). Furthermore, it is unclear if levels of presence remain stable over time, which has implications for the effectiveness of long-term applications of VR.

Additionally, the only unobtrusive way to administer questionnaires is after the virtual experience, which prohibits investigation of spatial presence on a moment-to-moment basis. Methods such as continuous presence sliders (i.e., moving a lever forward and backward to indicate presence level while in VR) have been used to capture temporal presence fluctuations, but face obtrusiveness issues. Break in presence counters (i.e., saying "now" at moments when the feeling of presence is lost while in VR) may be a useful alternative to sliders as they are less obtrusive to the experience of spatial presence.

Objective behavioral and physiological measures can also capture temporal fluctuations while avoiding obtrusiveness concerns and are less prone to participants' biases, however, they lose many of the aforementioned benefits of the subjective measures. Specifically, they tend to assess responses to task-specific situations that may or may not be indicative of spatial presence and have a multitude of explanations for why such behaviors or physiological responses would be observed.

Perhaps the most essential explanation for a moderate effect of immersiveness on presence is that because spatial presence is the subjective state of the user, it cannot be assumed that increasing immersiveness will necessarily increase presence. Thus, immersiveness can be thought of as the *system's potential to elicit presence*, with the user's reaction to the system determining the extent to which this potential is fulfilled. Understanding why increasing a system's immersiveness might not lead to a greater sense of being in the virtual environment requires consideration of the fundamental cognitive and perceptual processes the user must engage in (actively or not). After all, if spatial presence is a psychological state that can occur in non-mediated and mediated environments, the processes involved in becoming spatially present in the virtual world should be similar to those involved in feeling present in the physical world. There has been a recent push in the literature to incorporate these types of human abilities and limitations into current models of presence; of which theories on attention and spatial mental model development are most relevant.

Psychological Constructs in Virtual Reality Presence

Attention Allocation

To experience and interact with a mediated environment, the user must allocate attentional resources to the objects and events within the environment. The visual immersiveness of a head-mounted display (HMD) will be irrelevant if the user closes her or his eyes the whole time, or if attentional resources are not (at least in part) devoted to the virtual world. Generally speaking, attention is the process of taking notice and concentrating on some entity while ignoring other perceivable information (Jerald, 2015). Kim and Biocca (1997) emphasized the importance of attentional allocation in the formation of presence. Their model depicted how stimuli from the physical and virtual environment compete for the cognitive accessibility of the user. The role of attention was further explicated by Draper et al. (1998), who defined the concept of presence as a state that arises when a technology user commits her/his attentional resources to the technology-mediated world and inhibits perception of sensory information coming from the physical world (Draper et al., 1998). Both views claimed that the more attentional resources committed to virtual stimuli as opposed to physical stimuli, the more presence will be felt (Draper et al., 1998; Kim & Biocca, 1997)

However, this statement requires a slight modification to be true. A study by Slater, Usoh, and Steed (1994) investigated the effect of creating noise in the physical environment (dropping a cup and plate on the ground) during participants' virtual experiences, and found that presence was highest among individuals who reported the sound as having occurred within the virtual world. Thus, spatial presence will depend on the extent to which any incoming stimuli that are attended to are *classified by the user* as originating in the virtual environment, even if they actually occurred in the physical environment.

Spatial Mental Models

Attention to the virtual environment is necessary for experiencing presence, but it is also essential to understand why attention is necessary. A two-stage spatial presence model proposed by Wirth et al. (2007) theorized that focus of attention on the virtual environment enables media users to develop a spatial mental model of the environment. A mental model is an internal representation of external reality that is created and constantly updated to make sense of an environment (in this case, a virtual one) and predict future events within that environment (Craik, 1943; Johnson-Laird, 1983). In the first stage, media users attend to and process spatial cues (e.g., occlusion, motion parallax, interaural level/time differences) in the virtual environment, which help create and continuously update spatial representations of that environment. In the second stage, users begin testing perceptual hypotheses of self-location and possibilities to act within the virtual environment. Spatial presence occurs if the media user confirms these perceptual hypotheses, such that the virtual environment is the user's primary egocentric reference frame (i.e., users' perceived self-location, perceived possible actions, and mental capacities are all bound to the mediated space; (Wirth et al., 2007).

A key contribution of the Wirth et al. (2007) model was the separation of attentional resource allocation into automatic and controlled attention processes. Stimuli from the mediated environment can trigger attention involuntarily by evoking automatic processes such as an orienting response. Controlled attentional resources may also be consciously devoted to the environment via users' trait characteristics. For example, if the user is inherently more interested in the domain represented in the virtual environment, they may be more likely to devote attention to the environment. Though Wirth et al. (2007) mentioned that other trait variables such as intelligence, age, and gender could also impact presence via effects on automatic and controlled processes, the specific traits and mechanisms through which they might influence presence have been relatively underspecified in models of presence.

The Magnet Model of Spatial Presence

Based on an extensive review and literature synthesis, McGlynn and Rogers (in prep) developed a conceptual model of spatial presence called the Magnet Model of Spatial Presence (MMSP; Figure 1). This model was built upon the many strengths of the Wirth et al. (2007) model and aimed to address several of the aforementioned gaps in the presence literature. Specifically, the MMSP aggregates specific person variables that have been identified empirically as influencing presence and hypothesizes the mechanisms through which they might impact presence formation, maintenance, and break recovery.

The primary components of the model are as follows:

1. Physical & Virtual Magnets. The physical environment and the virtual environment compete, or 'magnetically pull' upon, the spatial presence of the user via physical and virtual stimuli, respectively. The stimuli coming from the physical and virtual environments determine the strength of the pull.
    a. Physical Stimuli: Stimuli that originate in the physical environment.
    b. Virtual Stimuli. Stimuli that originate in the virtual environment.
    c. Signal. Stimuli from either the physical or virtual environment that provide evidence of one's location in the *virtual* environment.
    d. Noise. Stimuli from either the physical or virtual environment that provide evidence of one's location in the *physical* environment.
2. Focus of Attention. Users can focus attention (may be automatic or controlled) on the incoming stimuli from the physical and virtual environments.

3. Stimulus Classification. On a moment-to-moment basis, the information that is attended to can either be classified by the user as originating in the physical environment (noise) or as originating in the virtual environment (signal). The perceptual hypotheses regarding perceived body and actions are tested on the basis of this information.
4. Perceived Body & Actions. Information that is classified as virtual will move users' perceived body and action possibilities (i.e. their spatial presence) in the positive direction, closer to the threshold. If this occurs consistently, the threshold will be crossed, indicating that the user has accepted the virtual environment as the primary egocentric reference frame (i.e., spatial presence is being experienced). Information that is classified as physical will move the users' perceived body and action possibilities in the negative direction, further away from the threshold. If this occurs consistently, the user will maintain the physical environment as the primary egocentric reference frame.
5. System Immersiveness/Threshold. The threshold represents the binary nature of spatial presence, the point at which virtual spatial presence is either on or off. The more immersive the system, the easier it is for the threshold to be crossed. In essence, if a highly immersive system is being used, threshold will be lower, indicating that it should take less time for spatial presence to occur. This time reduction is a result of a shorter amount of time needed to go through the stages of the Wirth (2007) model. Specifically, highly immersive systems project rich multimodal stimuli that

result in less time users need to spend constructing a spatial mental model of the virtual environment and testing the perceptual hypotheses.

6. Break in Presence. The processes of focusing attention and classifying stimuli continues even after the threshold is crossed and users are experiencing spatial presence. Thus, it is possible for a break in presence to occur, such that the user becomes suddenly aware of her/his actual location in the physical environment (Slater & Steed, 2000). When these breaks do occur, they may vary in strength such that they reset the entire process, shift the perceived body and actions to just below the threshold (regaining presence will be fairly quick and easy), or anywhere in between these two extremes.
7. Person Variables. There are a variety of person variables that can also influence this process. They impact this process via two primary mechanisms. First, person variables can also influence the ease of induction, such that all else being equal, certain individuals will be more likely than others to experience presence and it will take them less time interacting with the system for presence formation to occur. Second, certain individuals will be more or less able to maintain presence, such that some individuals might not experience a break in response to the same conflicting stimuli or event that causes a break in a different user. Similarly, individuals will vary in the extent that a break is detrimental to their experience (i.e., how far back in the process a break sets a person back) and in how quickly they are able to regain presence when breaks do occur.

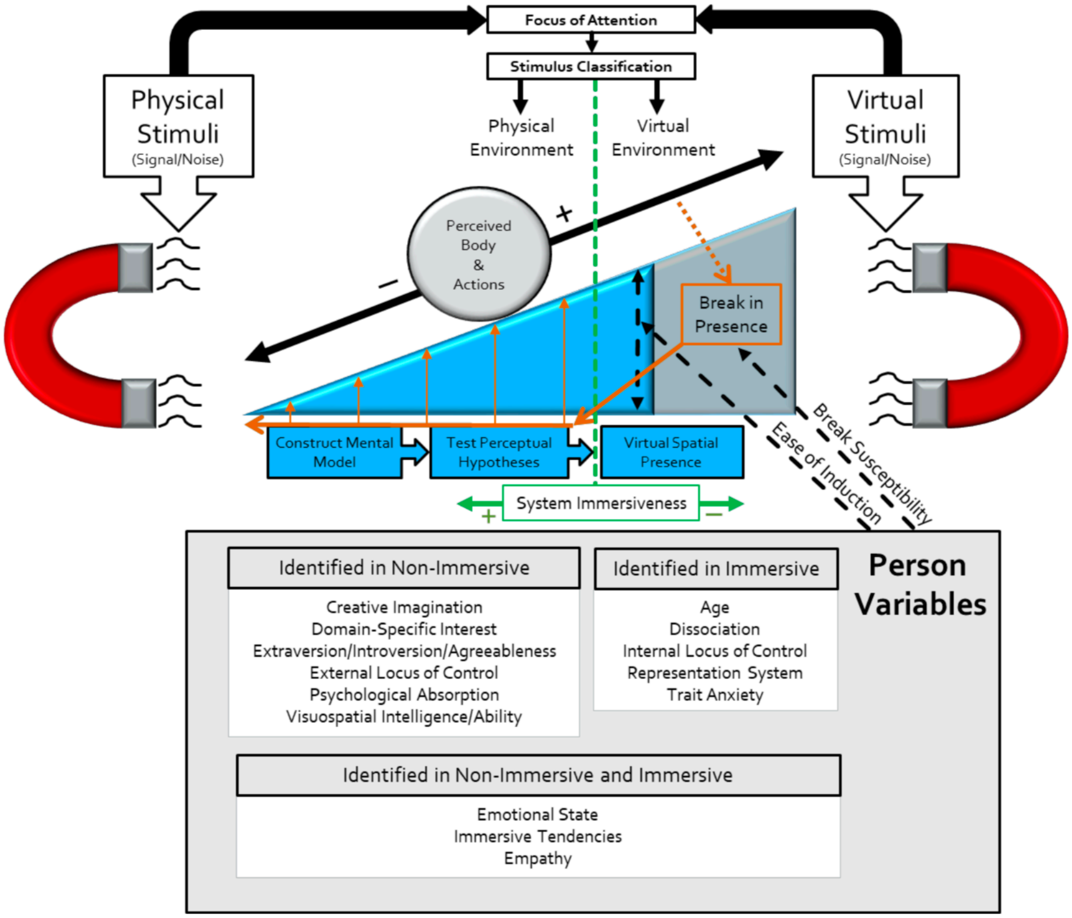


Figure 1. The Magnet Model of Spatial Presence (MMSP) in virtual reality (McGlynn & Rogers, in prep). Built as an extension to the two-stage Wirth (2007) model, which emphasized constructing a mental model of the virtual environment and testing perceptual hypotheses regarding one's perceived body and action possibilities. The MMSP emphasizes the conflict between physical and virtual stimuli as they vie for the VR user's focus of attention, how the user classifies these incoming stimuli influences their perceived body and actions, the role of the system immersiveness in setting a threshold, and the mechanisms of ease of induction (formation) and break susceptibility (maintenance) and how they may be influenced by person variables.

To summarize the model, individuals continuously focus attention on and classify incoming stimuli from both the physical and virtual environment (which are 'pulling' for the user's spatial presence). If the stimuli are consistently classified as virtual, users will cross the threshold (which depends on the immersiveness of the system) and experience presence such that the virtual environment becomes their primary egocentric reference frame. If the threshold is crossed in the opposite direction (the physical environment becomes the primary egocentric reference frame), a break in presence has occurred, and these breaks may vary in strength. Certain aspects of the process are dependent on user factors. Users will differ in the ease with which they are able to experience presence (i.e., presence formation), how present they become (i.e., presence level), their susceptibility to breaks in presence (i.e., presence maintenance), and how well they recover after a break in presence has occurred.

The strengths of this model are in explicating the potential roles of person factors, the distinction between findings using immersive and non-immersive systems (how the immersiveness of the system impacts the threshold), and the incorporation of presence maintenance and recovery from breaks. The goal of this dissertation is to empirically test components of this user-centered model of spatial presence in VR.

Age, Attention, & Spatial Presence in VR

There are many VR applications that have the potential to benefit older adults' physical, cognitive, and socio-emotional well-being. VR can be used for virtual exercise programs, which can have similar benefits as traditional workout techniques (Plante, Aldridge, Bogden, & Hanelin, 2003) but can sometimes have additional benefits for mood and can be more enjoyable and motivating than traditional techniques (Molina, Ricci, de Moraes, & Perracini, 2014; Plante et al., 2003). VR has also been used with older adults for easing chronic pain (Hoffman et al., 2004), training gait/balance (Hoffman et al., 2004), and training motor control (De Bruin, Schoene, Pichierri, & Smith, 2010).

Another application of VR is for cognitive screening to detect early declines by assessing visuospatial navigation skills (McGee et al., 2000) and performance on a diagnostic hallway walking task (Kim, Jang, Kim, Jung, & You, 2009). There is also evidence that VR can be used as a cognitive rehabilitation tool for correcting post-stroke hemispheric neglect (Kim et al., 2007).

There are numerous socio-emotional applications of VR for older adults. VR can be used for remote travel to tourist locations and museums (Guttentag, 2010), perhaps for individuals who are no longer physically or financially able to travel. VR could be used as a tool for social interaction with friends and family (Schroeder, 2002), whether it be simply for communication or to engage in some collaborative task or game remotely. Some other applications of VR are as a distraction for chemotherapy (Schneider & Hood, 2007), for fear exposure therapies (Hodges et al., 1995), and for easing anxiety and depression (Hoffman et al., 2004).

Because spatial presence is such an essential quality for VR applications to be effective and these applications have the potential to be extremely beneficial for older adults, it is necessary to understand if age-related changes impact older adults' ability to experience and/or the extent that they experience presence in VR. Only two studies have examined this relationship directly and with conflicting results. Bangay and Preston (1998) found a negative correlation between age and presence. Yet, they only used a single-item question to assess presence and their range of ages was from 5-54 years, so the age correlation may have been driven by the children in the study. Also, many of the age-related changes that might be expected to influence presence do not begin to occur on average until the mid-60s (Cavanaugh & Blanchard-Fields, 2014).

Schuemie, Abel, van der Mast, Krijn, and Emmelkamp (2005) found a positive relationship between age (18-62 years) and spatial presence using a validated questionnaire, but again the age span was rather young. Thus, for VR to be a useful tool for older adults, there is a need to better understand the true relationship between age and presence.

There are two primary age-related changes that can be expected to influence the presence process; changes in certain perceptual abilities, and changes in attentional abilities. Thus, the value of studying such a relationship is two-fold. First, identifying age-related differences in spatial presence (or lack thereof) and what drives these differences can inform designers of VR applications for older adults. Second, the extant literature on spatial presence in VR has almost exclusively included college students (ages ~18-21), who tend to be relatively high and exhibit little between-person variance in the perceptual and cognitive abilities involved in presence. As such, age can be used as a proxy for changes in these abilities, which has the potential to advance presence theory by providing insights into the nature of these abilities' influence on the entire presence process.

Implications of Age-Related Changes for Spatial Presence in Virtual Reality

Experiencing spatial presence while using these VR applications often improves or in some cases, is necessary, for the benefits to be realized. Yet, declines in certain perceptual and cognitive abilities that tend to occur with age are likely to impact the presence process in ways that have not been empirically investigated.

Declines tend to occur in eye structure around age 40 and in the retina around age 50 (Goldstein & Brockmole, 2016). Other visual changes occur as well such as an increase in the susceptibility to glare (Fisk, Czaja, Rogers, Charness, & Sharit, 2009). In the auditory system, older adults tend to have reduced sensitivity to high-pitched tones and a reduced ability to localize sounds (Cavanaugh & Blanchard-Fields, 2014).

Spatial presence in VR is a highly stimuli-dependent perceptual experience. It is unclear how potentially diminished sensory-perceptual abilities could alter this experience. One possibility is that slower perceptual processing abilities (Cavanaugh & Blanchard-Fields, 2014) will make it difficult for older adults to experience presence. However, it is also plausible that given certain diminished abilities, older adults will be less likely to notice perceptual incongruencies in the virtual environment and as a result, could experience a greater sense of presence than younger adults.

Perhaps the most likely reason for expecting age-related differences in spatial presence is that attention is a prerequisite for experiencing presence (Wirth et al., 2007) and that several different attentional abilities decline with age (Cavanaugh & Blanchard-Fields, 2014). Even in state-of-the-art VR, if the user chooses to not pay attention (e.g., focus on something else or close one's eyes) it will be impossible to experience spatial presence in the virtual environment. Maximizing attention on the virtual environment correlates with the extent that presence is experienced (Waterworth & Waterworth, 2001; Witmer & Singer, 1998). In immersive multimodal VR, it is thought that presence is greater because by activating several neural networks simultaneously they capture a maximum amount of users' attention and receptiveness (Hecht & Reiner, 2006). Although existing models of spatial presence in VR have emphasized the importance of attention in general, few explicitly state which type or types of attention are driving presence and/or if different types of attention are more relevant at different stages in the process. The Wirth et al. (2007) model did distinguish between automatic and controlled attention but even within these broad groupings, there are sub-domains that have implications for presence in VR, some of which change with age.

Age and Subtypes of Attention. Attention is a cognitive mechanism that governs which internal or external information is processed, while also determining which information is not processed (Chun, Golomb, & Turk-Browne, 2011). Automatic attentional abilities, which are used to direct attention to stimuli (e.g., alerting/preparatory response, orienting response), do not undergo substantial changes with age (Cavanaugh & Blanchard-Fields, 2014). Executive attentional abilities, which are what Wirth (2007) referred to as controlled attention, are used when there is a conflict between multiple attention cues (e.g., focused attention, divided attention, shifting attention; Mahoney, Verghese, Goldin, Lipton, & Holtzer, 2010). Controlled attentional abilities do tend to decline with age in ways that might be expected to influence the spatial presence process.

Focused attention is ability to select from the many factors or stimuli and focus on the one that you prefer or are automatically oriented to (Kahneman, 1973). Older adults have problems with certain aspects of focused attention, particularly in situations requiring inhibition of distracting or irrelevant information (Hasher & Zacks, 1988). Although older adults are able to focus on a particular task or set of stimuli, increasing the amount of irrelevant information within the task space will disproportionately affect older adults' ability to focus compared to younger adults' (Madden & Plude, 1993).

Divided attention is the ability to focus or concentrate on two or more things simultaneously. Older adults are just as *able* to multitask but perform tasks more slowly than younger adults. There are age-related divided attention decrements when tasks become complex (Cavanaugh & Blanchard-Fields, 2014; McDowd & Craik, 1988).

Shifting attention is the ability to flexibly switch attention back and forth between multiple tasks or mental sets. Older adults experience additional costs of needing to shift attention between multiple tasks or mental sets (Schnitzspahn, Stahl, Zeintl, Kaller, & Kliegel, 2013).

These age-related changes in certain types of attention could explain why older and younger adults' may differ in their experiences of presence in virtual reality. The changes also have implications for understanding the roles of these subtypes in the full spatial presence process, which a sound theory of spatial presence should specify. Of these subtypes, focused attention is the one that appears to be referenced most often. Witmer and Singer (1998) stated that presence is similar to selective attention, which "refers to the tendency to focus on selected information that is meaningful and of particular interest to the individual" (p. 226). Because older adults have inhibition difficulties in focused attention tasks, it follows that it may take them more time (or require more effort) to ignore the (irrelevant) physical environment and as a result, more time for presence formation to occur.

There are several open questions regarding the implications of age-related changes in attentional and perceptual abilities for the spatial presence process. It is not quite as simple as hypothesizing that older adults will either experience more or less presence because it is possible that their abilities and limitations will have different implications for presence at different stages in the process.

Regarding presence formation, age-related declines in the processing of sensory information and in the ability to inhibit irrelevant information may make them less likely to initially become present. Older adults may be better than younger adults at maintaining spatial presence for several reasons. In the absence of distractions within VR, older adults will likely be able to focus attention on the environment, but that environment or task may occupy a greater percentage of their attentional capacity. Because devoting more resources to the virtual environment is thought to increase presence (Hecht & Reiner, 2006), it is possible that older adults will experience higher levels of presence and for longer periods of time than younger adults (once the threshold is initially crossed). Younger adults may have a greater capacity for dividing attention simultaneously *across* the virtual and physical environments, which would be expected to decrease presence. Generally speaking, younger adults should also be more efficient at dividing attention *within* a VR experience. This would free up resources that could potentially be allocated to the physical environment (i.e., cause breaks in presence). Additionally, potential inconsistencies in the virtual stimuli may be less perceptible to older adults and as a result, less likely to break presence. However, due to declines in the ability to shift attention between multiple tasks, breaks in presence may be more detrimental to older adults' VR experience, particularly in their ability to regain presence once a break has occurred.

As a result of these age-related changes in perceptual and cognitive abilities, one plausible snapshot of the presence formation and maintenance process is as follows;

older adults will have a more difficult time becoming initially present (i.e., inhibition deficiency) and be more negatively impacted when breaks do occur (i.e., shifting attention deficiency), but experience a greater sense of presence and be less likely to experience breaks in presence once the threshold has been crossed (i.e., less able to divide attention across the virtual and physical environments and required to allocate more attention virtual environment). See Figure 2 for a conceptual diagram of within-experience presence for older and younger adults). In theory, spatial presence questionnaires capture the net levels presence in the virtual environment throughout an experience. Thus, only after identifying measures that are sensitive to temporal fluctuations in presence can we begin to understand these potentially complex relationships age-related changes and spatial presence formation, maintenance and break recovery.

Overview of Study

The overarching goal of this research was to understand potential age-related changes in presence formation, level, maintenance and break recovery, which had not been previously studied using appropriate age ranges. This research empirically tested components a theoretically-grounded conceptual model developed by McGlynn & Rogers (under review) as a first step towards understanding how age-related changes in perception and attention might influence spatial presence at various stages of the process. Previous models and research on spatial presence were limited in that; 1) they focused on overall levels of presence with little understanding of temporal fluctuations in presence and how to measure them, 2) they focused on varying the immersiveness of the system at the expense of understanding the role of the person using the system, 3) samples used were limited in range of presence-relevant abilities (i.e., college students), and (4 the abilities thought to be relevant to the process were often underspecified.

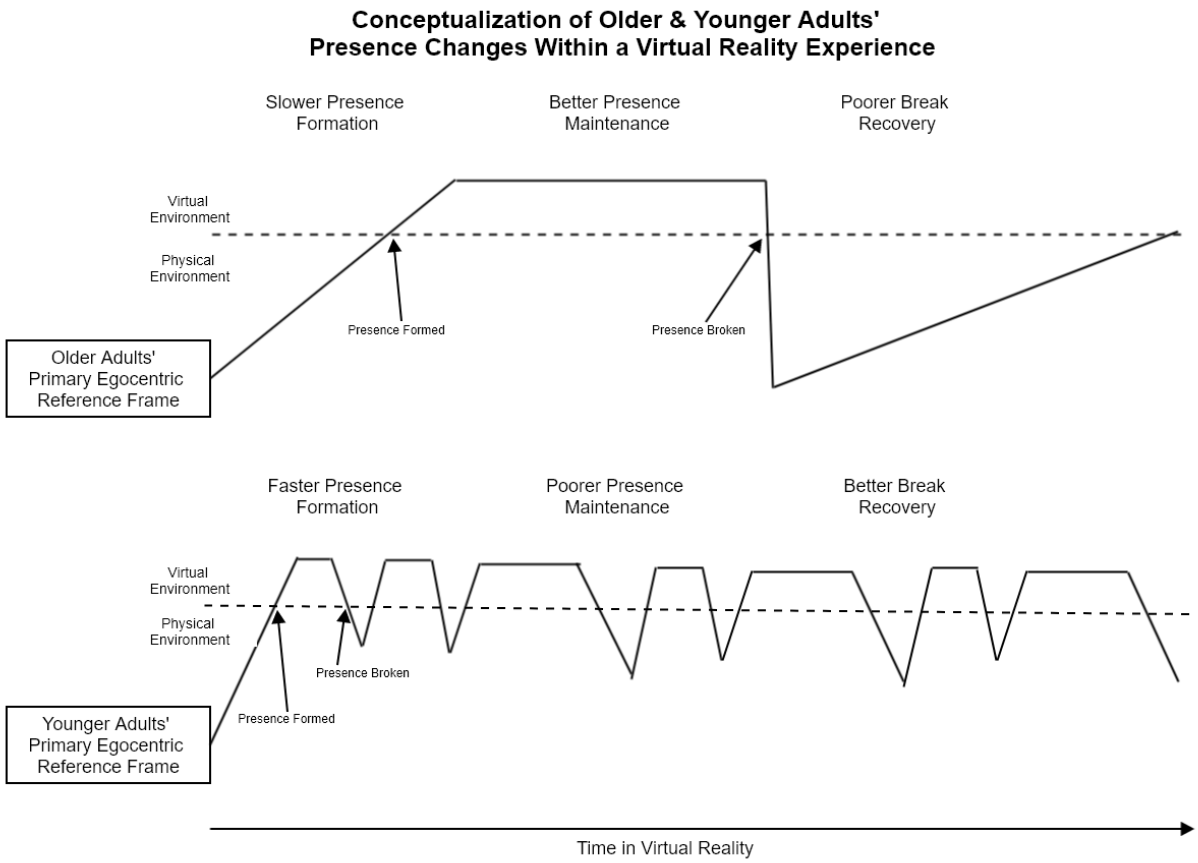


Figure 2. Conceptual diagram of within-experience fluctuations in virtual reality presence in for younger and older adults. Older adults' self-location and action possibilities (i.e., their primary egocentric reference frame) will move into the virtual environment more slowly than younger adults (i.e., slower presence formation), but they will be better able to maintain presence in the virtual environment more consistently than younger adults over time. When breaks in presence do occur, they will impact older adults more severely such that it will take them longer to regain their sense of presence in the virtual environment than younger adults.

The goals of this dissertation were to address these limitations by administering different types of measures of the full presence process using a highly immersive VR system which was kept constant. It also broadened the sample range to include people of varying cognitive abilities and measured specific types of cognitive abilities thought to be involved in the presence process. In doing so, we were able to begin to answer the following research questions:

1. How long does it take for spatial presence formation to occur?
2. To what extent do people experience spatial presence?

2.1. To what extent do levels of presence change over time/with experience

3. Once spatial presence is being experienced, how well do people maintain it?
4. If spatial presence is broken, how easy is it to regain?
5. How well do new and existing measurement methods capture the entire spatial presence process?
6. Do specific abilities account for differences in spatial presence?

Research questions 1-5 had an additional sub-question; are there age-related differences in presence formation, level, maintenance, break recovery, and measurement validity? This dissertation tested specific components of the MMSP. Figure 3 displays a simplified version of the MMSP and how the research questions related to different parts of the model.

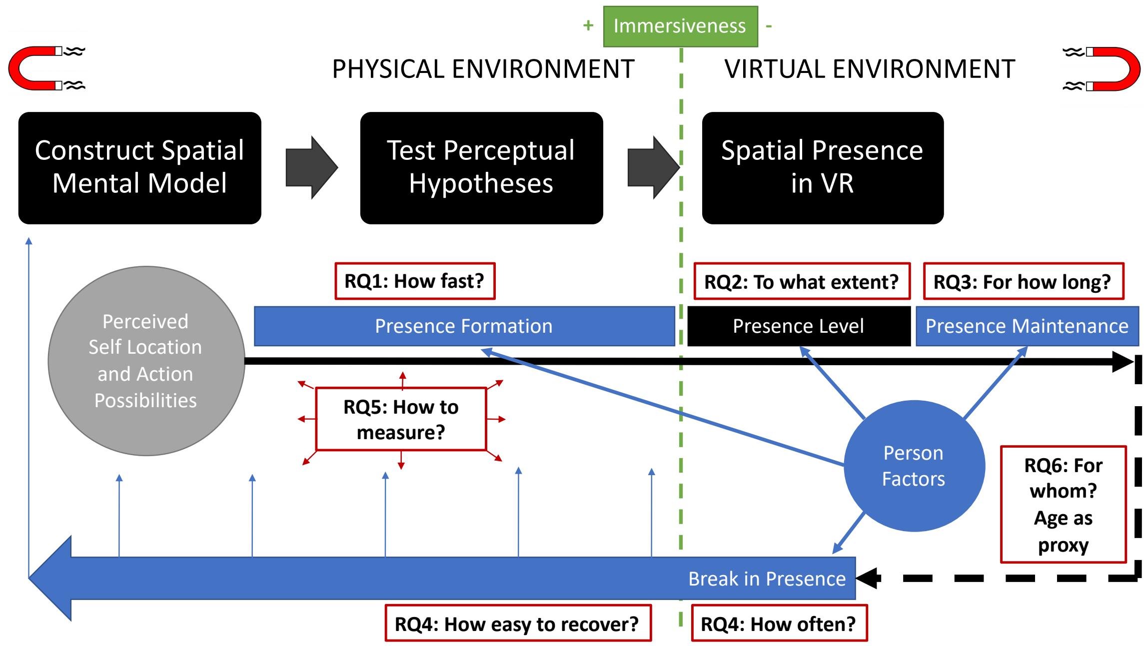


Figure 3. The Mini-Magnet Model of Spatial Presence (M-MMSP). Black boxes indicate components of the spatial presence process derived from the literature. Blue objects (boxes, circles, and arrows) indicate relatively unstudied components of the spatial presence process that were tested in this dissertation. Research questions are displayed in red text boxes.

CHAPTER 2: METHOD

Participants

Twenty-five younger adults (10 female, 15 male; *M* = 20, *SD* = 1.66, *Range* = 18-23) from the Georgia Institute of Technology undergraduate population participated in this study and received course credit for their participation. Twenty-six older adults were recruited from the Rehabilitation Engineering Research Center on Technologies to Support Aging-in-Place for People with Long-Term Disabilities (RERC TechSAge) participant registry. One older adult withdrew from the study prior to completion and received partial compensation. The other twenty-five (17 female, 8 male; *M* = 73.7, *SD* = 3.51, *Range* = 69-79) completed their participation and received $90 in compensation for their time. Participants were excluded if they owned a virtual reality system or had used virtual reality more than once. Participants were generally healthy, educated, and frequent users of technology (see Table 1 for additional demographic information).

Apparatus

The immersive VR system used was the HTC Vive, which included an HMD (and headphones), two motion tracked controllers, and two cameras. The HMD has two screens (one for each eye) with combined resolution of 2160 x 1200, 90 Hz refresh rate, and 110-degree field of view. Over-ear headphones provided directional audio and the HTC Vive controllers provided haptic feedback. The cameras enabled room-scale 360-degree motion tracking of the HMD and controllers. The system was powered using a CYBERPOWERPC Gamer Xtreme GXi10180A Desktop Gaming PC (Intel i7-7700 3.6GHz, NVIDIA GTX 1060 3GB, 8GB DDR4 RAM, 1TB 7200RPM HDD, Win 10 Home).

Table 1

Participant Demographic Information

Characteristic	Younger Adults	Older Adults	All Participants
Age (M ± SD) [Range]	20 ± 1.66 [18-23]	73.7 ± 3.51 [69-79]	
Gender (%)			
Female	10 (40)	17 (68)	27 (54)
Male	15 (60)	8 (32)	23 (46)
Education (%)			
High School Grad/GED	11 (44)	0	11 (44)
Vocational Training	0	2 (8)	2 (8)
Some College/Associate's	10 (40)	8 (32)	18 (36)
Bachelor's Degree	4 (16)	5 (20)	9 (18)
Master's Degree	0	6 (24)	6 (24)
Doctoral Degree	0	1 (4)	1 (2)
Ethnicity (%)			
White/Caucasian	13 (52)	13 (52)	26 (52)
Black/African-American	3 (12)	10 (40)	13 (26)
Asian	8 (32)	0	8 (16)
Multi-racial	1 (4)	1 (4)	2 (4)
General Health (%)			
Poor	0	0	0
Fair	1 (4)	4 (16)	5 (10)
Good	8 (32)	7 (28)	15 (30)
Very Good	11 (44)	10 (40)	21 (42)
Excellent	5 (20)	3 (12)	8 (16)
Technology Experience (Mean) [Possible Range]			
General Breadth	28.36 [0-36]	22.2 [0-36]	25.28 [0-36]
Frequency Profile	1.90 [0-3]	1.57 [0-3]	1.74 [0-3]

Virtual Experiences

There were two different virtual experiences used in this study; A task-free experience and an active experimental experience. The task-free experience was used to provide participants (who were all VR novices) with a sense of what it felt like to wear the headset and be in VR without needing to do anything or use the controllers. It also provided an opportunity for participants to become familiar with the post-experience questionnaires (see Appendix A for post-experience questionnaires) prior to the experimental sessions. Data from these questionnaires were not used in any of the analyses for this study. "The Blu: Whale Encounter" was used as the task-free virtual experience (hereto referred to as the "passive VR session"), during which participants were underwater on the deck of a sunken ship and were able to look around at various ocean creatures, culminating with a whale swimming up to the side of the ship before continuing to swim away. This experience was approximately two minutes long.

"VR The Diner Duo" by Whirlybird was used as the active experience (hereto referred to as the active VR experience). The premise of the game is the user is a hamburger chef in a diner who needs to complete customers' orders and hand them to a waiter/waitress for delivery. Completing the orders required viewing the orders, preparing order items (i.e., chopping or cooking), placing prepared items in the correct sequence on a plate, and handing the order to a waiter/waitress (Figure 4).

Selection of "Diner Duo" as the primary active virtual experience was based on several criteria:

1. Could be performed sitting down. The cooking station in the game was able to be adjusted for size and height so participants could sit and complete the task comfortably and safely.
2. Easy to learn/Minimal control requirements and no virtual interface. All tasks could be completed using two buttons (trigger and thumb press) and gesture controls. There was minimal requirement to memorize button mappings and there was no virtual control interface.
3. Engaged cognitive, perceptual, and motor abilities. The virtual experience engaged abilities that are relevant to potentially beneficial VR applications

(e.g., training, rehabilitation). To be successful, participants had to perform visual search for virtual objects, remember the preparation requirements for those objects, and manipulate those objects within the virtual environment.

4. Self-paced. There was no timer in "Training" mode, so participants had the ability to explore their surroundings and complete requests at their own pace and the experimenter was able to equate the length of the sessions across participants.
5. Task performance. Though task performance was not of primary interest (which was emphasized to participants prior to the VR sessions), it was necessary for the virtual task to have a performance component so the training completion criteria could be set.
6. Additional task/system selection criteria were based on data collection requirements necessary to answer the research questions. First, the HTC Vive allowed for video recording of the virtual environment, which enabled the administration of the retrospective video viewing session (details in Procedure). The HTC Vive could be partially used by the connected PC, which allowed the experimenter to have some control over the virtual environment without requiring participants to take off the headset (i.e., pause the experience, experimentally induce breaks in presence).

Figure 4. Diner Duo tasks. Viewing order (top left). Ingredient preparation – cooking (top right) and slicing (bottom left). Putting ingredients together and serving (bottom right).

Two modes of the active VR experience were used. One mode was called "Winter" and it had a difficulty component; if an order was not completed in a timely fashion, users received a strike. Three strikes resulted in a "Game Over". This mode was used as the criterion to determine if participants had reached an adequate level of performance. "Winter" mode will be referred to as the "active VR criterion test". The other mode was called "Training" and it was used for training participants on the task and for the experimental sessions. This mode was used because it did not have a difficulty component; orders could be completed at any pace without penalty. This enabled the experimenter to talk the participant through the task without the experience ending on its own (necessary for the active VR training sessions) and for the experimenter to set the duration of the experience (necessary for the active VR experimental sessions).

Objective performance was calculated for the active VR experimental sessions. Participants received points for completing orders, controlling for the difficulty of those orders (i.e., what was on the burger) by assigning different point values to the various order items. Point values were based on how much preparation was required for the item; Cheese = .5 points, Ketchup/Mustard = 1 point, Pickles = 1 point, Hamburgers = 1 point, Mushrooms = 2 points, Fish = 3 points. The possible points per order ranged from 1 to 9. A participant's individual performance score was the sum of her/his points on a given study day.

Materials

Demographics, Health, and Technology Experience

Demographics, health, and technology experience questionnaires were administered at baseline to obtain participants' descriptive information (Czaja et al., 2006). A questionnaire was also developed and administered to assess familiarity with a variety of virtual reality systems (HTC Vive, Google Cardboard, PlayStation VR, Oculus Rift, etc.). Participants indicated on a checklist if they had heard of, read about, seen pictures/videos of, seen pictures/videos of people using, or personally used these systems. Five younger adults had used VR once. All other participants had never used VR.

Cognitive Abilities

Several assessments were administered to assess participants' cognitive and perceptual abilities. The Useful Field of View (UFOV) task was administered on Day 2 as a measure of divided attention and focused attention, which were assessed separately in two subtests (Edwards et al., 2005). The Eriksen Flanker Task and the

Stroop Task were administered on Day 3 as measures of focused attention and response inhibition (Verbruggen, Liefooghe, & Vandierendonck, 2004). Trail Making Tests (TMT) A and B were administered on Day 2 as measures of shifting attention (TMT-B) and cognitive flexibility (TMT-B – TMT-A; Sanchez-Cubillo et al., 2009; Tombaugh, 2004). The Cube Comparison Test was administered on Day 1 as an assessment of spatial ability (French, Ekstrom, & Price, 1963). Table 2 displays the variable calculations for the cognitive ability measures used for the analyses in this dissertation.

Immersive Tendencies

The Immersive Tendencies questionnaire was administered as a measure of predisposition to becoming immersed in media (Witmer & Singer, 1998). It can be thought of as a trait spatial presence measure. Participants rated on a scale of 1-5 (strongly disagree – strongly agree) the extent that they tend to become deeply involved in media (e.g. TV, video games). Scores were calculated by taking the mean of the responses to the full questionnaire.

Spatial Presence

Table 3 displays the variable calculations for the spatial presence measures used for the analyses in this dissertation.

MEC-Spatial Presence Questionnaire. The MEC-Spatial Presence Questionnaire (MEC-SPQ) is a validated, multi-dimensional measure of levels of spatial presence. It was developed on the basis of the Wirth (2007) process model of spatial presence, which provided the foundation for the MMSP. As such, the primary analyses of spatial presence levels focused on data from this post-experience presence measure.

Table 2

Cognitive ability measure variable descriptions and calculations.

Assessment	**Measured Construct**	**Variable Calculation**
Cube Comparison	Spatial Ability	Number of correct minus number of incorrect
Useful Field of View	Divided Attention Focused Attention	Response times for each of the three UFOV parts
Stroop Task	Focused Attention Response Inhibition	Difference in reaction time on correct incongruent minus correct congruent trials
Flanker Task	Focused Attention Response Inhibition	Difference in reaction time on correct incongruent minus correct congruent trials
Trail Making Tests A & B	Shifting Attention (B) Cognitive Flexibility (B-A)	Time to completion for each part

The questionnaire included 7 dimensions, each with 4 items (6-item and 8-item versions of the MEC-SPQ also exist); Attention Allocation, Spatial Situation Model, Spatial Presence – a) Self-Location, b) Possible Actions, Cognitive Involvement, Suspension of Disbelief, Domain Specific Interest, and Visual Spatial Imagery. Response options ranged from 1 (strongly disagree) – 5 (strongly agree). Scores were calculated for each sub-domain by taking the 4-item mean from that domain. Spatial Presence:

Self-Location and Spatial Presence: Possible Actions are the sub-domains that represent the actual experience of spatial presence (these will sometimes just be referred to as Self-Location and Possible Actions, respectively). Attention Allocation and Spatial Situation Model represent what Wirth (2007) refers to as spatial presence process factors. Suspension of Disbelief and Cognitive Involvement are referred to as spatial presence state and action factors. See Table 3 for the MEC-SPQ items for these six sub-domains. Visual Spatial Imagery and Domain-Specific Interest are variables that address enduring trait-like variables and were used as descriptive rather than in primary analyses.

Igroup Presence Questionnaire. The Igroup Presence Questionnaire (IPQ) is a validated 14-item, multi-dimensional measure that included questions regarding Spatial Presence, Involvement, and Realness (Schubert, Friedmann, & Regenbrecht, 2001). The analyses in this dissertation focus on the MEC-SPQ because the theoretical foundation for this questionnaire aligns with the model of presence being tested in this study.

Break Counter. Breaks in presence were assessed using a break counter method (Slater & Steed, 2000). Participants were first shown three bi-stable images (see Figure 5) and asked to describe what they saw. After participants were able to "see" both interpretations of each bi-stable image, the experimenter stated that similar to how by shifting perspective it was possible to see either one version of the bi-stable image or the other, participants might experience a similar sensation during the virtual reality sessions in terms of where they felt their bodies were located.

Table 3

MEC-SPQ Questionnaire Items

Sub-Domain	Items
Attention Allocation	I devoted my whole attention to the virtual environment I Concentrated on the virtual environment The virtual environment captured my senses I dedicated myself completely to the virtual environment
Spatial Situation Model (SSM)	I was able to imagine the arrangement of the spaces presented in the virtual environment very well I had a precise idea of the spatial surroundings presented in the virtual environment I was able to make a good estimate of the size of the presented space Even now, I still have a concrete mental image of the spatial environment
Spatial Presence: Self-Location	I felt like I was actually there in the virtual environment It was as though my true location had shifted into the virtual environment I felt as though I was physically present in the virtual environment It seemed as though I actually took part in the action of the virtual environment
Spatial Presence: Possible Actions	I had the impression that I could be active in the virtual environment I felt like I could move around among the objects in the virtual environment The objects in the virtual environment gave me the feeling that I could do things with them It seemed to me that I could do whatever I wanted in the virtual environment
Cognitive Involvement	I thought most about things having to do with the virtual environment I thoroughly considered what the things in the environment had to do with one another The virtual environment activated my thinking I thought about whether the virtual environment could be of use to me
Suspension of Disbelief	I concentrated on whether there were any inconsistencies in the virtual environment I didn’t really pay attention to the existence of errors on inconsistencies in the virtual environment I took a critical viewpoint of the virtual environment It was not important for me whether the virtual environment contained errors or contradictions

Participants were instructed to say the word "Now" whenever they felt that their sense of self-location had transitioned from the virtual environment to the physical environment. This method has been shown to correlate with presence as measured by self-report questionnaires, such that individuals who experience more breaks in presence also report lower levels of presence overall (Slater & Steed, 2000). Scores were calculated by taking the sums of participants' reports of the word "Now" during the active VR session.

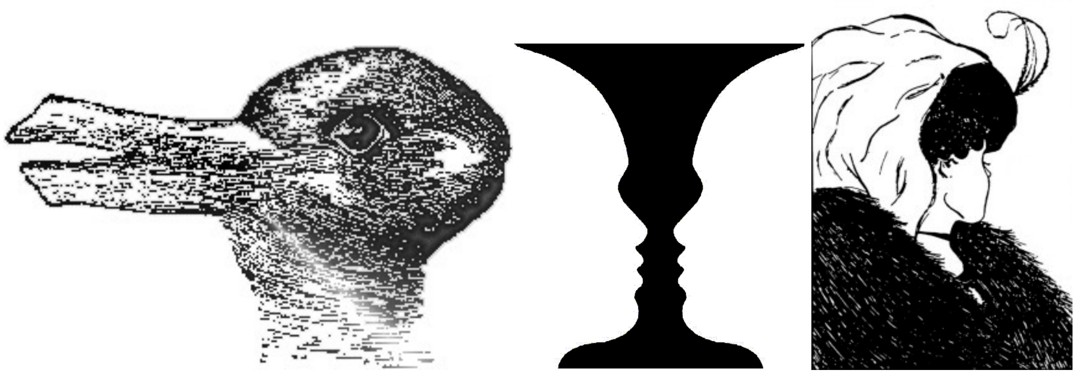


Figure 5. Bi-stable images. Duck/rabbit (left), Vase/faces (center), Old woman/young woman (right).

Retrospective Presence Slider. Presence sliders have been used to capture temporal changes in presence, such that individuals will provide moment-to-moment adjustments on a physical slider. Moving the slider forward indicates individuals' "sense of being" is more in the virtual environment and backward indicates "sense of being" is more in the physical environment. This method has shown to relate to presence in non-immersive environments (IJsselsteijn, de Ridder, Hamberg, Bouwhuis, & Freeman, 1998), but been criticized for usage in immersive VR as being directly intrusive to the experience because it introduces a secondary task. To avoid this limitation, participants in this study did a retrospective presence slider session, wherein they viewed a video of their active VR session immediately after it occurred and used the touchpad of the Vive controller to continuously indicate their presence at that moment in the experience. Specifically, participants were asked to place their finger on the touchpad and move their finger forward (more virtually present) and backward (more physically present) to indicate at each moment during their last virtual experience, the location in which they felt that they were physically located. A legend was provided by the experimenter (see Appendix C) and kept on the table in front of the participant for the duration of the video viewing.

The Vive controller touchpad collected the vertical position of the thumb every .01 seconds during the video viewing sessions. The data ranged from -1 to 1, with -1 to -.1 indicating physical presence, .1 to 1 indicating virtual presence, and -.1 to .1 being indeterminant. The data used in these analyses were derived from participants' thumb positions every 1 second. To assess presence formation, the presence slider data were summarized by counting the number of participants who first formed presence (i.e., first reported a score in the .1 to 1 range) within 10 seconds of the video viewing session. The variable used for level of presence was the mean score over the course of the session. Presence maintenance was determined by calculating the percentage of time spent virtually present (% of total seconds within .1 to 1), physically present (% of total seconds within -1 to -.1), and indeterminant (% of total seconds within -.1 to .1).

Break Susceptibility & Recovery Questionnaire. The Break Susceptibility & Recovery Questionnaire (BSRQ) was developed for this study to explicitly assess how easily participants perceived it was for them to experience a break in presence and how intrusive breaks in presence were to the virtual experience if/when they did occur.

Participants were asked to indicate the extent that they agreed or disagreed (1 = Strongly Disagree – 5 = Strongly Agree) with statements about breaks in presence. There was also an option for "Not Applicable: I did not experience a break in presence". Due to evidence that participants did not understand this questionnaire, it was not used in the analyses for this study. See Appendix D for the distribution of responses to the items on this questionnaire.

Semi-Structured Interview. A semi-structured interview was administered at the end of the final study day. Participants were asked about the experimentally induced breaks in presence, to define presence, and to reflect on their experiences of presence throughout the study (e.g., what enhanced and detracted from it, how long it took them to first experience it, the extent that it was experienced throughout the study). Most of the questions required participants to provide specific responses such as "Yes/No" and "Physically Present/Virtually Present". The responses to these were summed per question, the outcome of which was a count of the number of participants (within age groups and overall) who provided a given a response to the interview question. Questions with responses that were more open-ended in nature (e.g., "If you were to describe presence to a friend, what would you say?", what caused breaks in presence) were used for verbatim quotes to highlight certain observations, but were not coded or counted for response frequency. See Appendix E for the interview script.

Table 4

Presence measure descriptions and variable calculation.

Assessment	Measured Construct	Variable Calculation
MEC-SPQ	Level of Spatial Presence & Sub-Domains (not including	Mean of 4-items from each sub-domain
Break Counter	Spatial Presence Maintenance	Sum of times saying the word "Now" during Active VR sessions
Retrospective Presence Slider	Spatial Presence Formation	Mean presence slider level viewing video of active VR sessions
	Level of Spatial Presence	Percentage of seconds spent virtually & physically present according to slider
	Spatial Presence Maintenance	Number of participants who first formed virtual presence within a given amount of time
Semi-Structured Interview	Spatial Presence Formation	Number of responses for specific choice-based questions
	Spatial Presence Maintenance	
	Recovery from Breaks in Presence	

Affect

The short form of the International Positive and Negative Affect Schedule (I-PANAS-SF; Thomas, 2007) was administered to measure the potential impact of the VR experience on participants' positive and negative emotions and the possible relationship between emotion and presence. This assessment consists of five positive (e.g., alert, inspired) and five negative (e.g., afraid, upset) emotions. Participants indicated on a 5-point scale (1 = not at all, 5 = extremely) the extent to which they felt each of these emotions during the virtual experience they had just participated in. Inclusion of this scale was exploratory and not used in the analyses for this study.

Simulator Sickness. The Simulator Sickness Questionnaire was administered after the task-free VR session and the active experimental session. Participants indicated the extent that they were currently experiencing any of 15 symptoms (e.g., nausea, dizziness, blurred vision). Responses on this assessment were immediately monitored by the experimenter to determine if it was safe for the study session to continue. No participants indicated that they were experiencing any of the symptoms more than slightly, so no study sessions were affected due to simulator sickness. This questionnaire was not used in the analyses for this study.

Workload. The NASA-TLX is a validated 6-dimension measure design to obtain subjective workload immediately after a task (Hart & Staveland, 1988). This was administered after the passive VR sessions and the active VR experimental sessions each day to determine perceived levels of Mental, Physical, and Temporal Demands, Frustration, Effort, and Performance during each experience as a whole. Response options ranged from 0 (i.e., low demand) to 100 (i.e., high demand) for each of the dimensions.

Procedure

This research study took place at the Center for Assistive Technology and Environmental Access (CATEA). Older adults who expressed interest in participating in the study were sent an online survey with several questionnaires prior to the first day of participation. Younger adults completed these same questionnaires on a computer during the first day of their participation. The first page of the survey was the consent form, which informed participants that clicking through to the next page indicated that they were providing their consent to participate in the study. The questionnaires in the online survey included; demographics, health, technology experience, virtual reality familiarity, the immersive tendencies questionnaire, and the visuo-spatial imagery component of the MEC-SPQ. The on-site study took part over the course of three days. Each day included:

1. Cognitive ability assessments
2. A passive VR session
3. An active VR training session
4. An active VR criterion test session
5. An active VR experimental session

Prior to the active VR training session, participants were walked through a tutorial packet describing the tasks involved in the Diner Duo experience and the controls required to complete these tasks (see Appendix F). The active VR training session lasted in 10-minute intervals, during which the participant was allowed to ask the experimenter questions and for assistance as needed. Once the participant was able to complete three sandwiches and had successfully interacted with every possible sandwich ingredient at least once, they received a 5-minute break and then participated in the active VR criterion test session. Training was considered “passed” if the participant was able to complete at least three sandwich orders in this mode without receiving a Game Over and without experimenter intervention. If training was “failed”, participants received a 5-minute break, the tutorial packet was reviewed, and another active VR training session was conducted. Following this, another active VR criterion test session was conducted. If the participant passed the criterion test session, after a 5-minute break, the 10-minute active VR experimental session began, during which the experimenter did not interact with the participant. The post-experience battery, which included the MEC-SPQ, the IPQ, the SSQ, the NASA-TLX, and the I-PANAS-SF, was administered after each passive VR session and each active VR experimental session. Administration of cognitive/perceptual ability assessments was distributed across the three days and occurred at the very beginning of each day. The passive VR sessions remained the same across days. The tutorial packet was reviewed on Days 2 and 3 for all participants, but the active VR training session was only conducted for younger participants on Days 2 and 3 if they failed the active VR criterion test. The active VR experimental sessions differed slightly each day:

- Day 1: No temporally-sensitive assessments (baseline)
- Day 2: Break in presence counter and retrospective presence slider
- Day 3: Break in presence counter and retrospective presence slider. Breaks in presence were induced experimentally two times, one third and two thirds of the way through the session. Breaks were induced by the experimenter using the Vive's outward facing camera to overlay a digital version of the physical environment into the VR headset as an overt visual reminder of the participant's physical location (Figure 6). These lasted approximately 10 seconds each, during which the experimenter walked across the participant's field of view, touched the motion tracker on the

opposite side of the room, and then returned across the participant's field of view to the experimenter's PC and removed the digital overlay.

Following the experimental sessions on Days 2 and 3, participants completed the break susceptibility/recovery questionnaire. The semi-structured interview was conducted at the end of Day 3, after which participants were debriefed. Participants were compensated $90 total for their time. See Figure 7 for a diagram of the procedure.

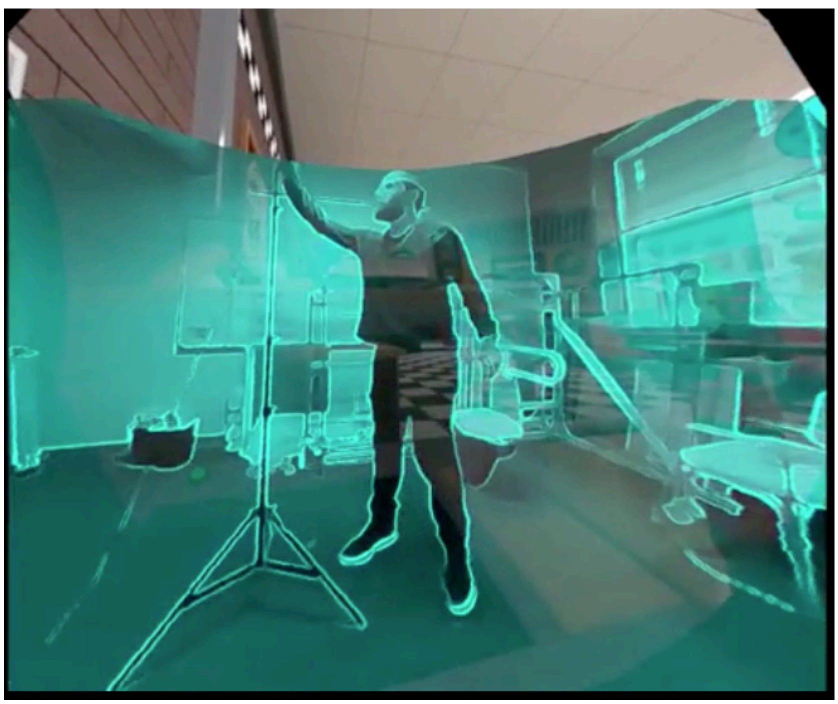


Figure 6. Experimentally induced break in presence on Day 3. Digital representation of the physical room was displayed in the headset for ~10 seconds as the experimenter walked across the room, touched the motion tracker, and then returned back across the participant's field of view and removed the digital overlay.

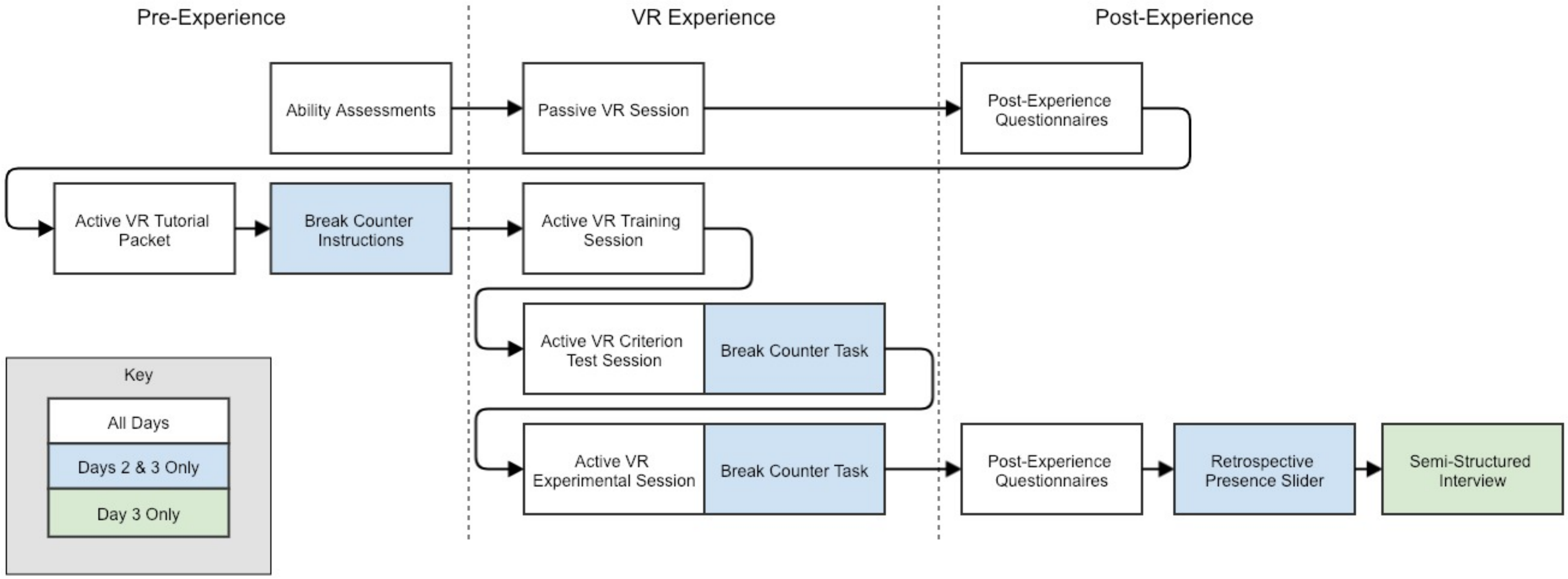


Figure 7. Study Procedure

CHAPTER 3: RESULTS

Analysis Overview

Data from one semi-structured interview (younger), two Stroop scores (older), one Flanker score (older), and one initial questionnaire (older) are missing data due to computer, equipment, and/or experimenter error. These missing data are reflected in the analyses that follow.

Descriptive information regarding VR-related descriptive information is presented for Immersive Tendencies, Domain-Specific Interest, Visuo-Spatial Imagery, Objective Performance, and the six sub-scales of the NASA-TLX. Younger and older adults were similar in their domain-specific interest and self-reported visuo-spatial imagery abilities. Younger adults had slightly higher immersive tendencies, such that they agreed more with statements regarding their general inclination to become deeply involved in various media (e.g., books, movies). Younger adults' objective performance (i.e., active VR session orders completed) was higher than older adults', but overall, objective performance increased over the course of the three days. Subjective workload was generally lower for younger adults, but overall, participants felt that their performance was improving and that the demands of the task were declining as the study continued. See Table 6 for descriptive data regarding the VR-related trait measures and performance/workload during the experiences.

Because the experimentally induced break in presence on Day 3 influenced the break counter and retrospective presence slider data, only Day 2 data were used in the analyses that follow. See Table 5 for an overview of the measures used to address the research questions in this study.

Table 5

Research Questions and Measures Used

Research Question	Component of Interest	Measures Used
How long does it take for presence formation to occur?*	Presence Formation	Day 2 Presence Slider Semi-Structured Interview
To what extent do people experience presence?**	Level of Presence	MEC-SPQ Day 2 Presence Slider Semi-Structured Interview
Once presence has occurred, how well do people maintain it?*	Presence Maintenance	Day 2 Break in Presence Counter Day 2 Presence Slider Semi-Structured Interview
If presence is broken, how easy is it to regain?*	Recovery from Breaks in Presence	Semi-Structured Interview
How well do new and existing presence measures capture the full process?*	Convergent Validity and Utility of Multiple Measures	MEC-SPQ Day 2 Presence Slider Day 2 Break in Presence Counter
Do ability factors predict spatial presence differences?	Individual Differences	Ability Measures MEC-SPQ Day 2 Presence Slider Day 2 Break in Presence Counter

*Are there age-related differences?
** Are there age-related differences and/or differences across days?

VR-Related Traits, Engagement and Enjoyment

Prior to examining aspects of the spatial presence process, VR-related trait measures were analyzed to determine if younger and older adults differed in Immersive Tendencies Questionnaire, Domain-Specific Interest, and Visuo-Spatial Imagery. Younger adults were significantly higher than older adults in Immersive Tendencies ($t(47) = 3.52$, $p = .001$), but did not differ significantly in Domain-Specific Interest ($t(48) = 1.96$, $p = .055$) or Visuo-Spatial Imagery ($t(47) = 0.35$, $p = .467$). Thus, younger adults were more likely to agree with statements regarding their predisposition to become involved in media (e.g., TV, video games). See Table 6 for means and standard deviations of these measures.

Table 6

Means and Standard Deviations for VR Trait Variables

Measure	Younger Adults Mean (SD)	Older Adults Mean (SD)	All Participants Mean (SD)
Immersive Tendencies	4.42 (.87)	3.57 (.80)	4.00 (.93)
Domain-Specific Interest (MEC-SPQ)	3.56 (.89)	3.10 (.76)	3.33 (.85)
Visuo-Spatial Imagery (MEC-SPQ)	3.45 (.95)	3.31 (1.00)	3.38 (.97)

Though the primary focus of this study was not to determine how engaged or how much participants enjoyed their VR experiences, for VR applications to be effective tools for training and interventions, it is necessary for them to possess these qualities. Thus, it was also critical to understand participants' general experiences with and perceptions of VR. This was especially the case for the older participants, who did not grow up in a time where these types of advanced technologies are as pervasive as they are today.

Though younger adults' performance was higher than older adults', both age groups showed improvements over the course of the study, suggesting that they were engaged in the task and remained engaged across days. They also felt that their performance was improving and in general, felt that the demands of the task were decreasing as the study progressed. See Table 7 for means and standard deviations.

Anecdotally, participants generally seemed to enjoy their VR experiences. Of note is that no participants dropped out of the study. We also asked participants if they would like to have the VR system for their home if it were offered to them for free. All but one of the younger adults said "Yes". The older adults were somewhat mixed. Of the 17 older adults that were asked this question, 11 said "Yes", 1 said they would like to know more about it first, 1 said if it could provide a benefit for themselves or their significant other, and 4 said “No”.

In sum, both younger and older adults appeared to be engaged in their VR experiences and found them to be enjoyable. This provides some evidence that these types of VR tasks, which engage cognitive-perceptual-motor abilities and are somewhat physically and mentally demanding, may be able to be used for VR trainings and interventions by people of varying abilities.

Spatial Presence Formation

The first aim of this dissertation was to investigate the spatial presence formation process and potential age-related differences. Presence formation was defined as the amount of time it took for the feeling of virtual presence to first occur. In general, spatial presence formation occurred very rapidly and there was little evidence that the formation process differed across age groups. 45 of the 49 participants indicated being virtually within the first 30 seconds of the experience using the presence slider. Of the remaining four, three were younger adults and one was an older adult. 42 of the 49 participants said that they became virtually present quickly (e.g., “instantly”, “immediately”, “a couple of seconds”) when asked to estimate the amount of time it took them after putting on the headset to first become virtually present. Of the remaining seven, six were younger adults. The longest amount of time reported by any participant was “a minute or so”.

Table 7

Means and Standard Deviations for VR Performance and Workload

Measure	Younger Adults Mean (SD)	Older Adults Mean (SD)	All Participants Mean (SD)
Objective Performance			
Day 1	83.94 (18.28)	34.64 (17.19)	59.29 (30.47)
Day 2	101.96 (21.85)	40.42 (19.12)	71.19 (37.13)
Day 3	100.70 (36.28)	46.08 (17.32)	73.39 (36.28)
Performance (NASA-TLX)			
Day 1	29.40 (25.22)	44.40 (30.93)	36.90 (28.94)
Day 2	30.80 (26.29)	54.00 (27.00)	42.40 (28.86)
Day 3	36.80 (30.99)	56.00 (34.73)	46.40 (33.99)
Mental Demand			
Day 1	60.68 (21.42)	73.00 (21.18)	66.84 (21.98
Day 2	53.20 (26.29)	66.80 (32.14)	60.00 (30.17)
Day 3	48.40 (27.72)	65.00 (31.85)	56.70 (30.71)
Physical Demand			
Day 1	48.00 (24.32)	61.40 (30.43)	54.70 (28.09)
Day 2	44.00 (31.75)	54.20 (30.81)	49.10 (31.39)
Day 3	40.80 (30.16)	55.20 (33.90)	56.70 (30.72)
Temporal Demand			
Day 1	62.40 (20.21)	58.40 (30.34)	60.40 (25.59)
Day 2	53.20 (27.00)	57.00 (30.69)	55.10 (26.83)
Day 3	52.40 (24.07)	54.20 (28.10)	53.30 (25.90)
Effort			
Day 1	59.80 (25.47)	61.60 (26.10)	60.70 (25.54)
Day 2	49.00 (21.13)	60.60 (30.60)	54.80 (28.32)
Day 3	48.20 (26.96)	61.20 (29.34)	54.70 (28.65)
Frustration			
Day 1	19.40 (19.32)	29.40 (26.27)	24.40 (23.38)
Day 2	16.40 (15.71)	32.40 (27.05)	24.40 (23.35)
Day 3	13.40 (13.90)	24.60 (21.50)	19.00 (18.79)

Level of Spatial Presence

The next goal was to determine, once presence formation had occurred, what was the overall level of spatial presence that was experienced, or *how present* did people? Overall, levels of presence were high (Figure 8). Presence was significantly higher than the midpoint on the presence slider, as determined by a one sample t-test comparing the overall mean slider scores to the midpoint of the scale (see Table 8). The finding of high levels of presence was corroborated by the MEC-SPQ means scores. One sample t-test compared mean scores on each day for the MEC-SPQ sub-domains of Attention Allocation, Spatial Situation Model, Spatial Presence: Self-Location, Spatial

Presence: Possible Actions, Suspension of Disbelief, and Cognitive Involvement to the midpoint of those scales (3, neutral). These scores were significantly higher than the midpoint on every day except for Suspension of Disbelief on Day 2.

In general, the data did not provide evidence in support of age-related differences in levels of presence. Slider presence mean scores were significantly higher than the midpoint for both age groups (see Figure 9 for average presence level over the course of the session and Figure 10 for the overall mean scores of the session). MEC-SPQ scores were significantly higher than the midpoint for both age groups across all sub-domains except for Suspension of Disbelief (See Figures 11 and 12). Younger adults' Suspension of Disbelief was not higher than the midpoint on Day 2. Older adults' Suspension of Disbelief was not higher than the midpoint on Days 2 or 3. There were two sub-domains of the MEC-SPQ for which there were two medium-large sized main effects of age group as evidenced by 3 (time) x 2 (age group) repeated measures ANOVAs on these sub-domains (see Table 9 for the results of these analyses). Older adults were significantly higher than younger adults on Attention Allocation, with age accounting for 11% of the variance in Attention Allocation, which was a medium-large sized effect (d = .67).

Table 8

Group means and results of the overall one sample t-test for the active VR MEC-SPQ

MEC-SPQ Sub-Domain	Younger Adult Mean (SD)	Older Adult Mean (SD)	Overall Mean (SD)	p

Attention Allocation				
Day 1	4.82 (.29)	4.89 (.28)	4.86 (.29)	.00*
Day 2	4.41 (.64)	4.81 (.35	4.61 (.55)	.00*
Day 3	4.41 (.70)	4.69 (.45)	4.55 (.60)	.00*
Spatial Situation Model				
Day 1	4.46 (.69)	4.52 (.48)	4.49 (.59)	.00*
Day 2	4.53 (.49)	4.40 (.51)	4.47 (.50)	.00*
Day 3	4.56 (.55)	4.32 (.54)	4.44 (.55)	.00*
Self-Location				
Day 1	4.37 (.64)	4.64 (.40)	4.51 (.54)	.00*
Day 2	4.16 (.68)	4.43 (.58)	4.30 (.64)	.00*
Day 3	4.46 (.69)	4.41 (.53)	4.29 (.62)	.00*
Possible Actions				
Day 1	4.53 (.52)	4.21 (.59)	4.37 (.57)	.00*
Day 2	4.49 (.64)	4.05 (.70)	4.27 (.70)	.00*
Day 3	4.46 (.68)	4.03 (.78)	4.25 (.75)	.00*
Cognitive Involvement				
Day 1	4.24 (.44)	4.12 (.45)	4.18 (.44)	.00*
Day 2	3.88 (.71)	4.10 (.52)	3.99 (.63)	.00*
Day 3	4.04 (.66)	4.09 (.42)	4.07 (.55)	.00*
Suspension of Disbelief				
Day 1	3.39 (.80)	3.30 (.85)	3.35 (.82)	.00*
Day 2	3.02 (.83)	3.23 (.74)	3.13 (.79)	.27
Day 3	3.33 (.88)	3.56 (.65)	3.45 (.78)	.00*

* Overall mean was significantly higher than the midpoint of the scale (3.00, “Neutral”) at p<.05 level

Younger adults were significantly higher than older adults on Possible Actions, with age accounting for 11% of the variance in Possible Actions, which was a medium-large sized effect (d =.69). However, these age differences were no longer significant after applying a Bonferroni correction controlling for the number of ANOVAs run ($p = .05/6 = .008$).

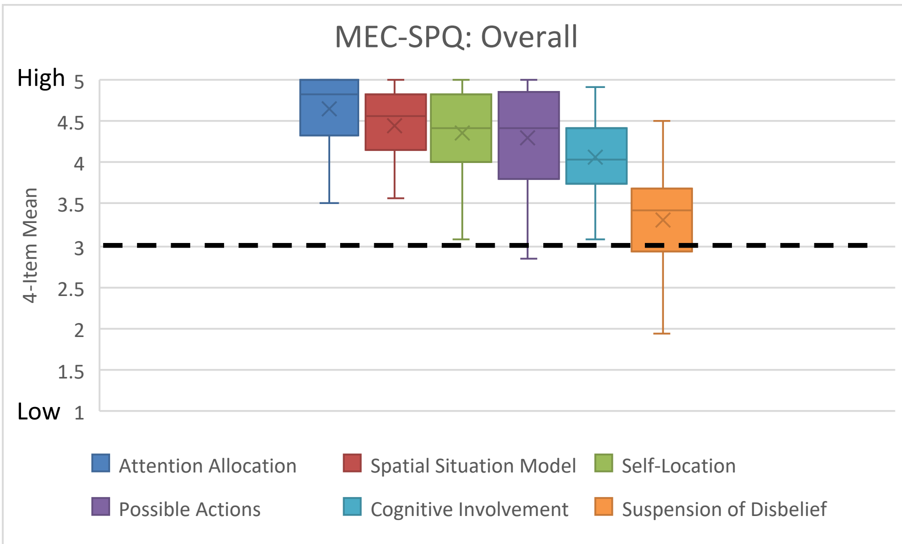


Figure 8. Boxplots for each of the MEC-SPQ sub-domains.

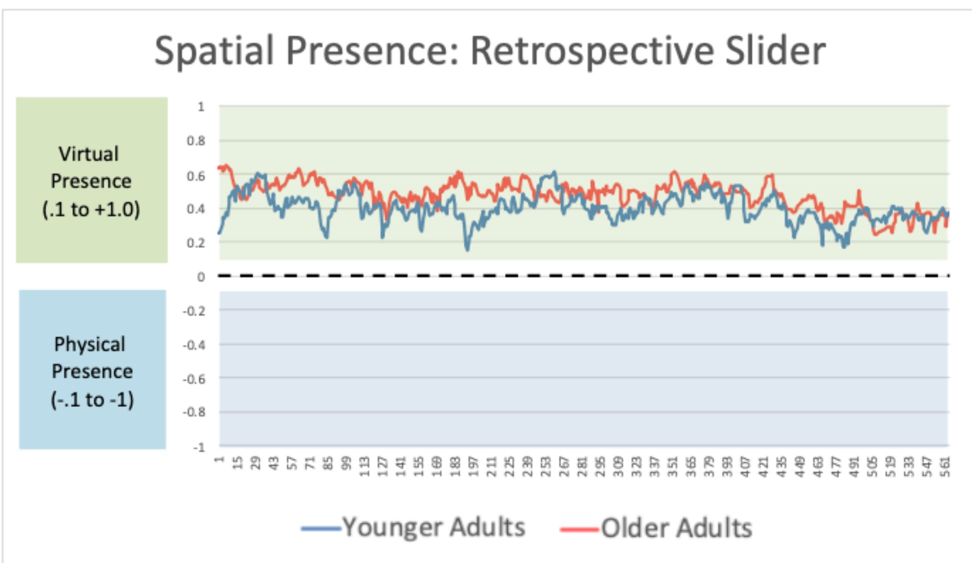


Figure 9. Mean presence slider scores over time for younger and older adults.

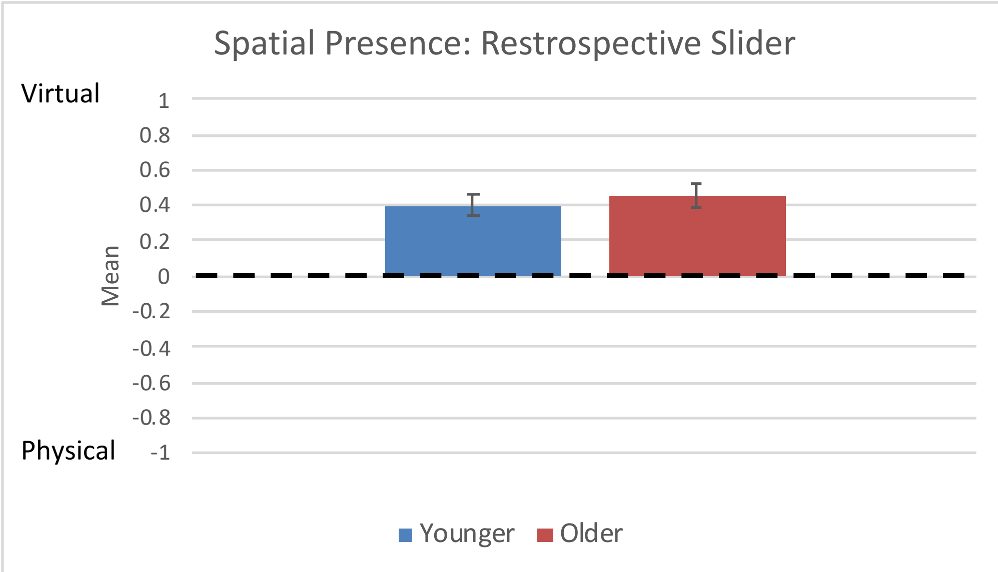


Figure 10. Overall mean presence slider scores for younger and older adults.

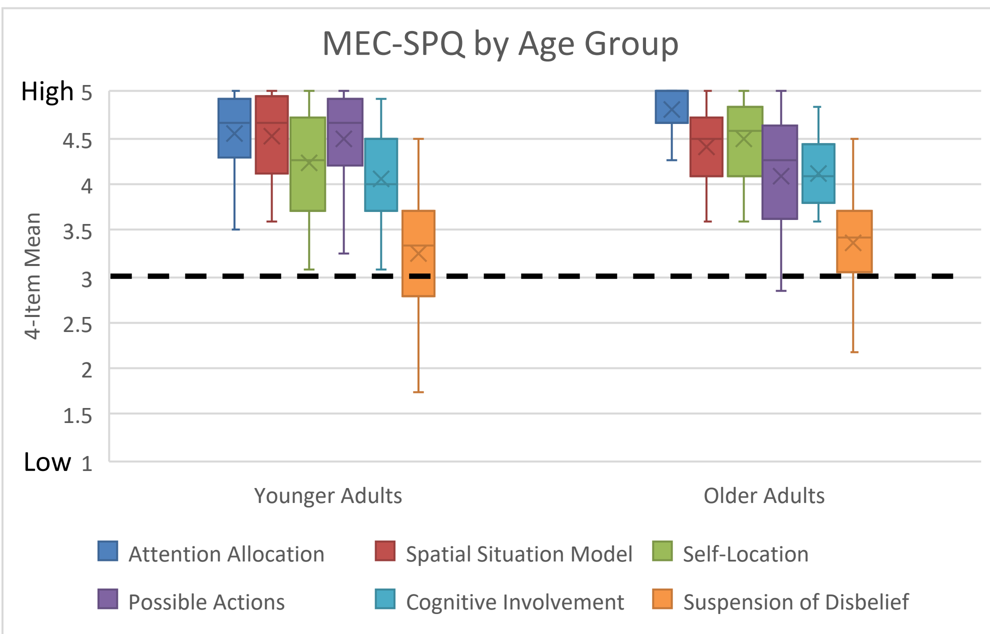


Figure 11. Boxplots for each of the MEC-SPQ sub-domains for younger and older adults.

There were main effects of time on some of the MEC-SPQ sub-domains, ranging from small-medium to medium-large in size. Bonferroni corrections were applied to all post-hoc analyses.

Attention Allocation was significantly higher on Day 1 compared to Day 2 (mean difference .25, p=.003), which was a medium sized effect (*d* = .56). It was also higher on Day 1 compared to Day 3 (mean difference .31, p=.001), which was a medium-large sized effect (*d* = .65). Study day accounted for 17% of the variance in Attention Allocation.

Self-Location was significantly higher on Day 1 compared to Day 2 (mean difference .21, p=.033), which was a small-medium sized effect (*d* = .35). It was also higher on Day 1 compared to Day 3 (mean difference .22, p=.046), which was a small-medium sized effect (*d* = .38). Study day accounted for 10% of the variance in Self-Location.

Suspension of Disbelief was significantly higher on Day 3 compared to Day 2 (mean difference .32, p=.009), which was a small-medium sized effect (*d* = .41). Study day accounted for 9% of the variance in Suspension of Disbelief. Regardless of these effects, it is worth note that although presence level differed on certain days for a few sub-domains, it remained higher than the midpoint across days for all sub-domains except for Day 2 Suspension of Disbelief.

These results suggested that participants generally experienced high levels of presence throughout the study with little evidence of significant differences across age group and time for most of the MEC-SPQ sub-domains.

Table 9

Two-Way Repeated Measures ANOVA Table for MEC-SPQ

MEC-SPQ Domain	Source	df	MS	F	*p*	η_p^2
Attention Allocation	Time	2	1.31	9.56	.000**	.17
	Age	1	2.34	5.62	.022*	.11
	Time x Age	2	.35	.26	.083	.05
Spatial Situation Model	Time	2	.03	.19	.828	.00
	Age	1	.40	.70	.406	.01
	Time x Age	2	.29	1.74	.181	.04
Self-Location	Time	2	.77	5.10	.008**	.10
	Age	1	2.60	3.43	.070	.07
	Time x Age	2	.00	.01	.989	.00
Possible Actions	Time	2	.22	1.46	.238	.03
	Age	1	5.90	5.98	.018*	.11
	Time x Age	2	.04	.31	.579	.01
Cognitive Involvement	Time	2	.46	2.91	.059	.06
	Age	1	.09	.16	.688	.00
	Time x Age	2	.36	2.30	.106	.05
Suspension of Disbelief	Time	2	1.34	4.90	.009**	.09
	Age	1	.51	.38	.542	.01
	Time x Age	2	.40	1.47	.236	.03

*$p < 0.05$
**$p < 0.01$

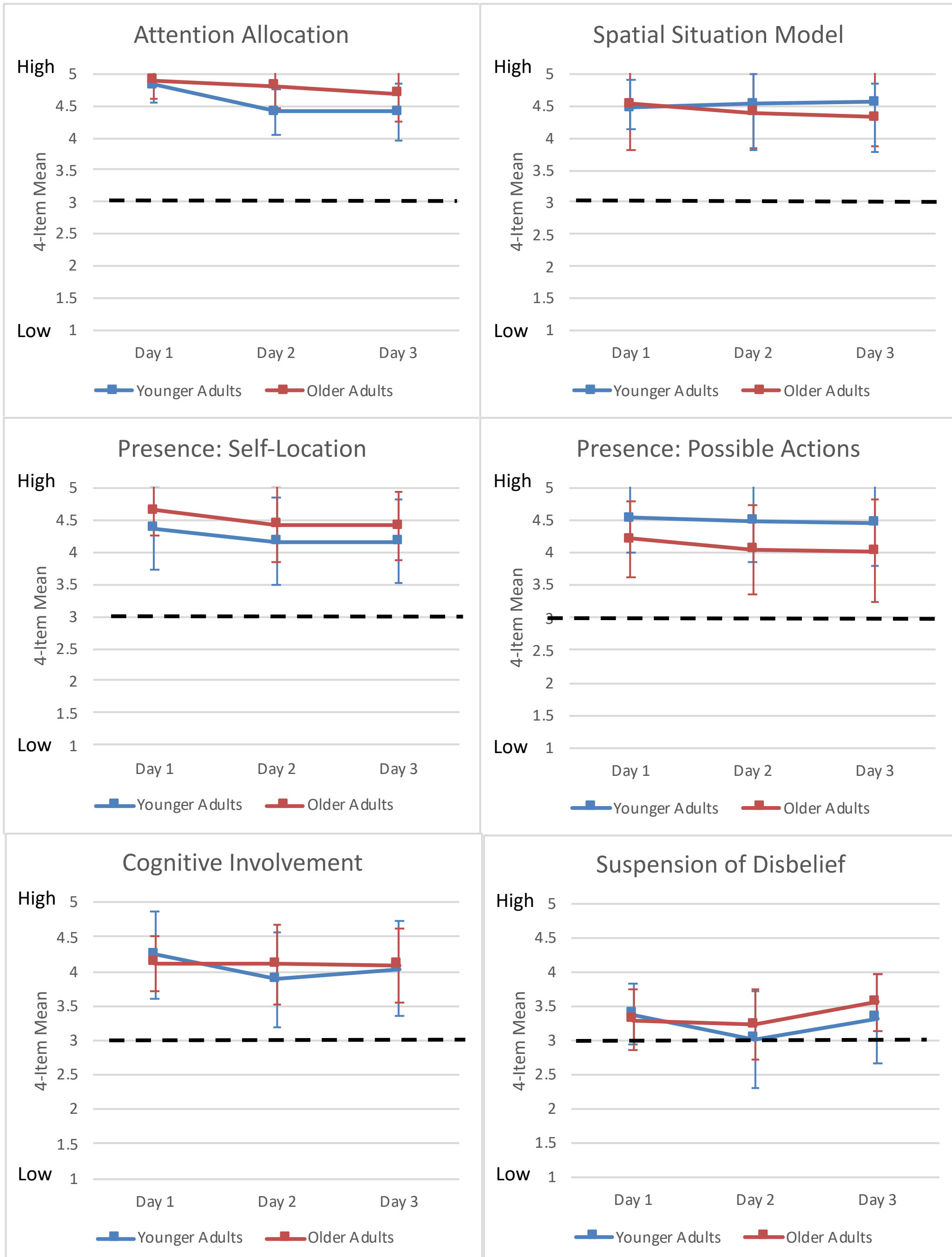


Figure 12. MEC-SPQ sub-domains by age group and study day. Means were significantly higher than the midpoint every day and for every sub-domain except Suspension of Disbelief on Day 2. Main effects of Time were observed for Attention Allocation (Day 1 higher than Days 2 and 3), Self-Location (Day 1 higher than Days 2 and 3), and Suspension of Disbelief (Day 3 higher than Day 2). Main effects of Age were observed for Attention Allocation (older adults higher than younger adults) and Possible Actions (younger adults higher than older adults). No significant interaction effects were observed.

Maintenance of Presence

The next aim was to determine, now that presence had been formed and some level of presence had been attained, how well people were able to maintain presence in the virtual environment. Presence maintenance was defined as how often breaks in presence occurred as well as the total length of time that was spent virtually present relative to physically present.

Though there was some variability across participants (see Figure 13), presence maintenance was high, such that participants reported being virtually present most of the time during their VR sessions (see Figure 14). Presence slider scores for the active VR session indicated that overall, participants spent a greater percentage of the total session seconds virtually present (79.8%) compared to physically present (14.1%). 6.1% of the time was indeterminant (i.e., between -.1 and .1 on the slider). Additionally, when asked to estimate the percentage of total time in VR spent virtually vs. physically present, participants estimated that they were virtually present 88.2% of the time compared to physically present 11.8% of the time. Despite being virtually present most of the time, participants did report experiencing some breaks in presence. Overall, there were 140 breaks in presence reported during the active VR session. The average number of breaks in presence reported were generally low, with participants reporting an average of 2.8 breaks total or .28 breaks per minute over the course of the 10-minute session.

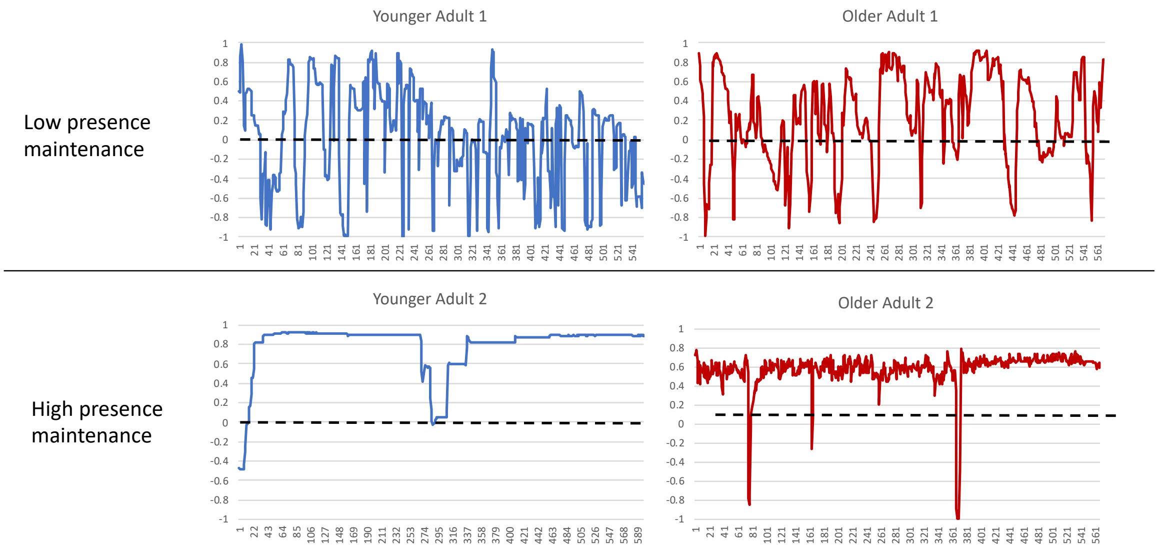


Figure 13. Individual slider presence line graphs for two younger and two older adults. Top panel represents low presence maintenance. Bottom panel represents high presence maintenance

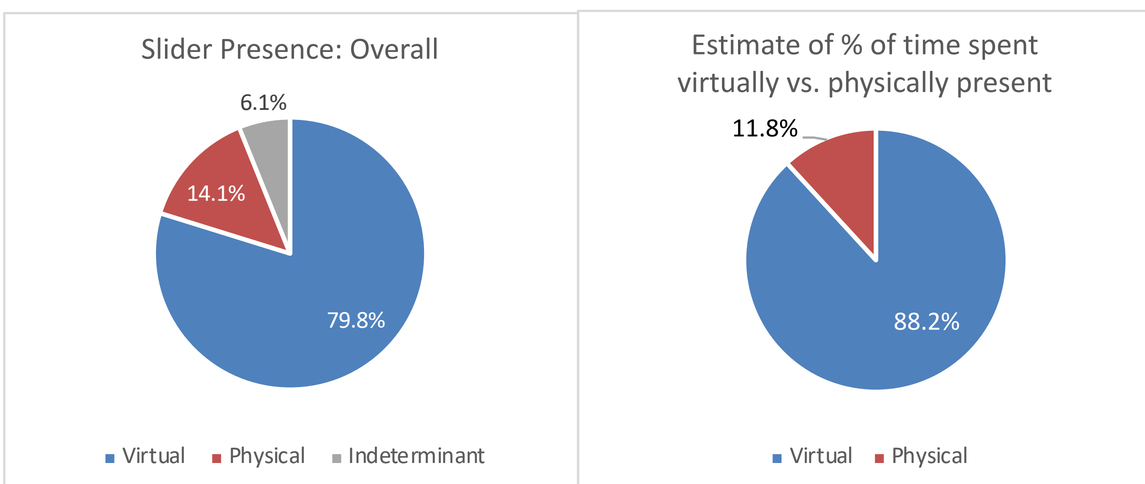


Figure 14. Percentage of time spent virtually vs. physically present as determined by the slider (left) and the semi-structured interview (right).

Comparing these data across age groups, there did not appear to be substantial differences in overall time spent virtually present vs. physically present as indicated by the slider percentage and the self-reported percentage from the semi-structured interview (see Figure 15).

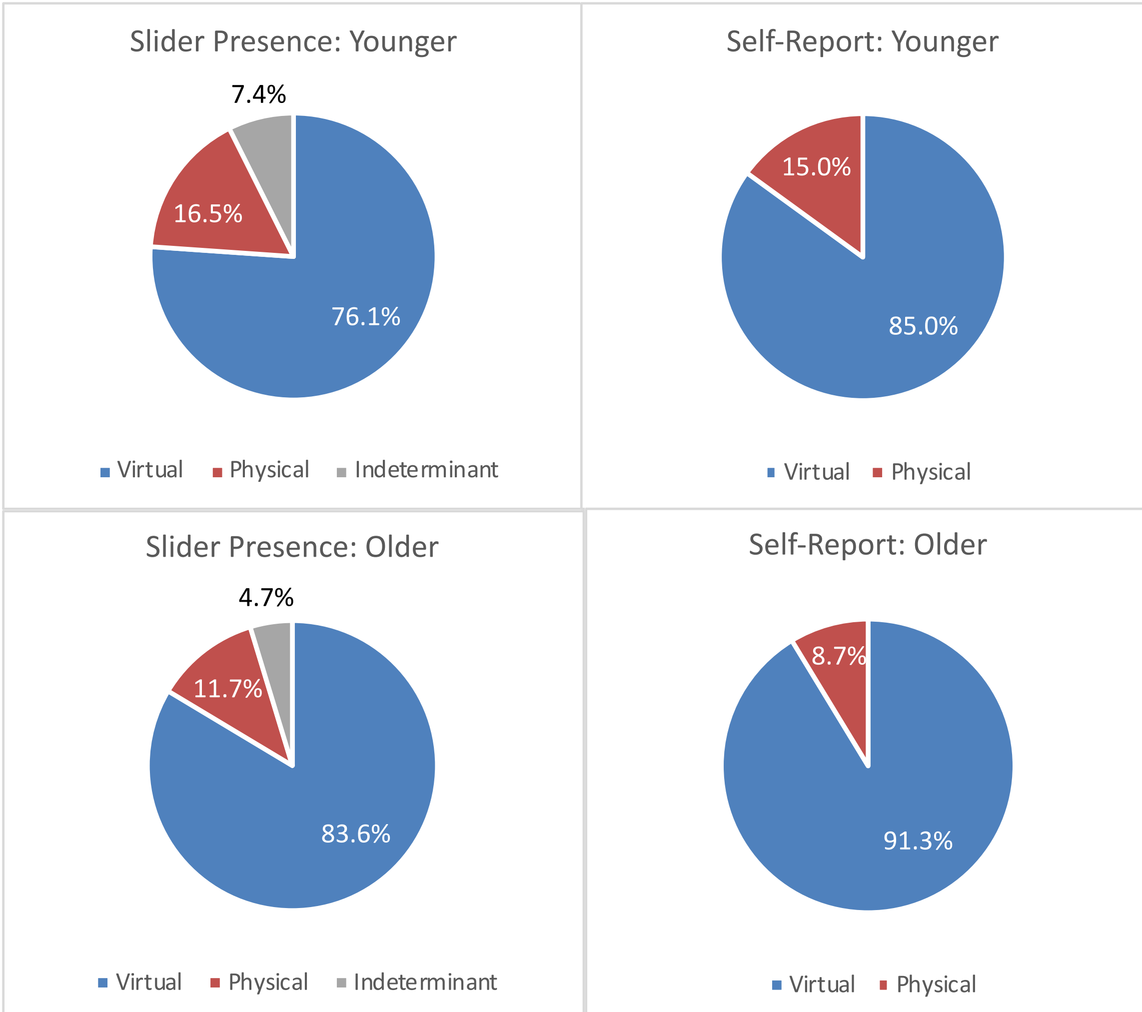


Figure 15. Percentage of active VR session time spent virtually present and physically present by age (top = younger, bottom = older) on the slider (left) and the semi-structured interview (right).

Yet, there was a difference between younger and older adults in the number of breaks in presence reported as determined by a Mann-Whitney U test (See Figure 16). Younger adults reported a significantly greater number of breaks in presence than older adults (Younger, *Mdn* = 3; Older, *Mdn* = 0, U=142.5, p = .001). Of note is that only 11 of the 25 older participants reported at least one break in presence whereas 23 of the 25 younger participants reported at least one break in presence.

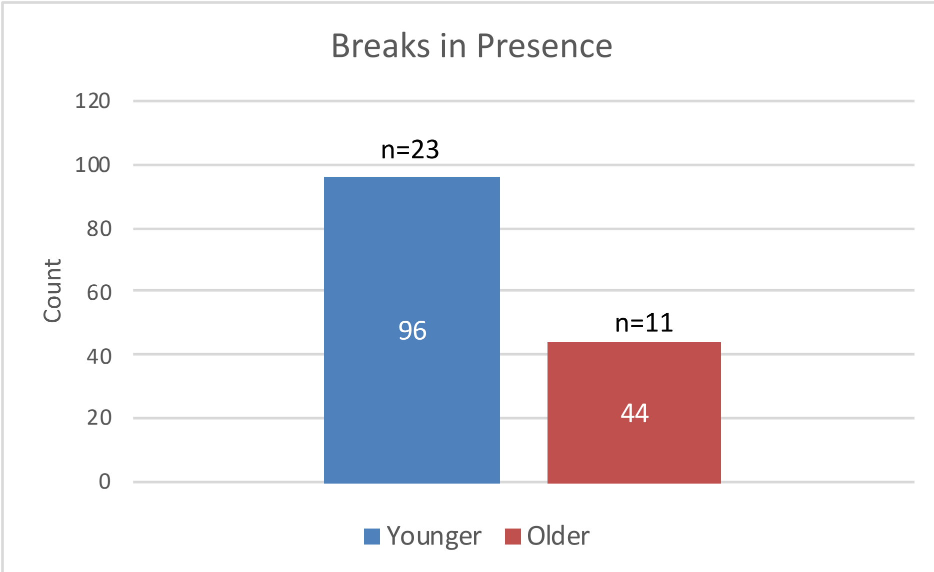


Figure 16. Total number of breaks in presence reported for younger vs. older adults. Younger adults reported significantly more breaks in presence.

In sum, breaks in presence (i.e., presence maintenance failures) did occur and did so more frequently for younger adults than older adults. Though overall, most people reported at least one break in presence, slightly more than half of the older adults did not report any at all, suggesting higher presence maintenance for older adults. However, people maintained presence in the virtual environment for the majority of the time spent in VR and this did not differ across age groups. Thus, it could be the case that when breaks in presence occurred, they were not substantially intrusive and so people were able to recover quickly from breaks in presence.

Recovery from Breaks in Presence

The results on presence formation and level indicated that across both age groups, formation occurred quickly and level of presence was high. Age differences were observed in presence maintenance, such that younger adults' presence was broken more frequently than older adults'. However, because the total amount of time spent virtually present was still high for both groups, it could have been the case that (similar to the observation of rapid presence formation) recovery from breaks in presence also occurred rapidly. Break recovery was defined as the ease or difficulty with which participants were able to regain their sense of virtual presence after a break in presence and the amount of time it took them to do so.

To assess break recovery, breaks in presence were experimentally induced on Day 3 of the study. As a manipulation check, we asked participants to describe what they saw when the breaks in presence occurred. 43 of the 49 participants indicated that they saw their physical body, the experimenter's physical body, and/or the room, suggesting that most participants did realize that they were suddenly seeing the physical environment.

Additionally, the induced break was effective for most, but not all participants. Participants were asked whether they felt more virtually or physically present during the induced breaks in presence. 34 said they felt more physically present, 13 said they felt more virtually present, and 2 said they felt both physical and virtual simultaneously regarding the first induced break. Regarding the second induced break, 38 said physical and 11 said virtual. To ensure that we were obtaining perceptions of break recovery from individuals who experienced breaks in presence, the following response counts are only from participants who reported feeling more "physical" during the induced breaks.

In the semi-structured interview, participants were asked how difficult they found it to be to regain their sense of virtual presence after each break occurred. Regarding the first induced break overall, 29 of the 34 participants said it was easy to recover from. Regarding the second induced break, 32 of the 38 participants said it was easy to recover from (See Figure 17).

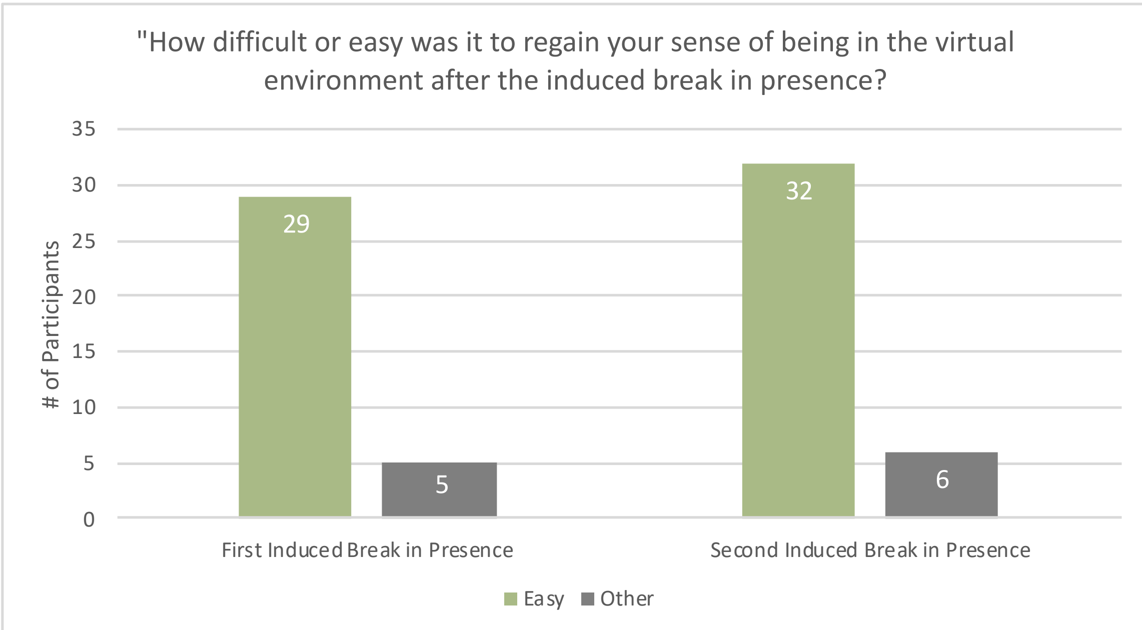


Figure 17. Ease of regaining sense of virtual presence after break induction overall.

Comparing across age groups, during the first break induction, 19 of the 34 participants who responded "Physical" were younger adults and 15 were older adults. For the second break induction, 22 who responded "Physical" were younger adults and 16 were older adults. Only one "Other" response came from an older adult (of the 31 total older adult responses across both induced breaks), whereas 10 "Other" responses came from younger adults (of the 41 total younger responses across both breaks). See Figure 18.

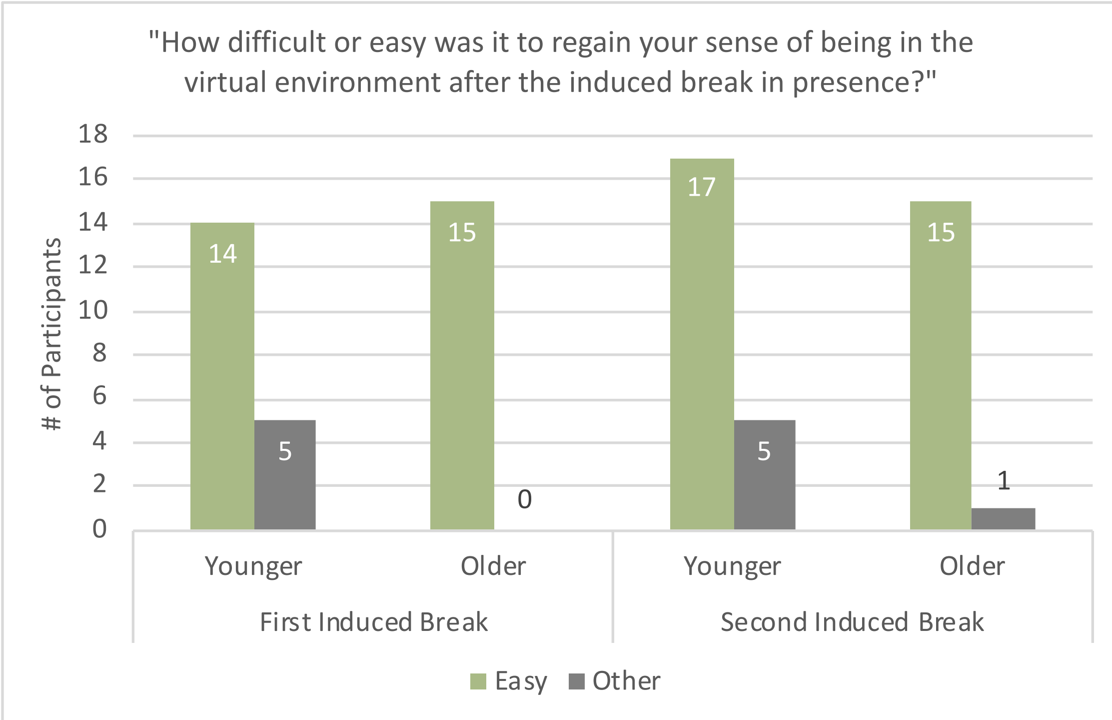


Figure 18. Ease of regaining sense of virtual presence after break induction for younger and older adults.

Though more younger adults reported "Other" responses, these did not necessarily indicate that it was hard to recover, but included responses such as "harder than the first time" or "still kind of dazed" or "more difficult than the first [induced break]". However, another consideration is that the 6 participants who did not mention anything from the physical environment were all older adults. Thus, the visual overlay of the physical room may have been less perceptible by older adults (though they may have still realized they were seeing the physical environment even if it wasn't reported). Yet in general, most participants felt that recovering from breaks in presence was easy, which makes sense in conjunction with the finding that younger adults reported more breaks in presence but still spent a large proportion of their total time present in the virtual environment. Though more breaks in presence occurred for the younger adults, they were still relatively easy to recover from.

Convergent Validity and Utility of the Spatial Presence Measures

The most common method of measuring presence is through post-experience questionnaires such as the MEC-SPQ, which captures the overall level of presence experienced after a VR session. One of the primary goals of this dissertation was to provide insights on the validity of measures presence that were sensitive to within-experience fluctuations in presence, which provided an opportunity to gain more granular understanding of the entire presence process. Two measures that are more temporally sensitive are the break in presence counter and the presence slider. Specifically, the aim was to address the following questions about these measures by comparing them to the results of the post-experience questionnaires and the semi-structured interview; are they intrusive to the spatial presence experience, are they fair to use for people of varying abilities (i.e., younger vs. older adults), and do they correlate with other validated measures of presence?

Break in Presence Counter

The main criticism of the break in counter method is that by introducing a prospective memory task (saying "Now" when a break is experience), it forces users to devote some attention to instructions in the physical environment, thereby reducing their virtual presence. In this study, the break counter was not conducted on Day 1 of the study. If the task of reporting breaks was intrusive to the experience of spatial presence, it would have been expected to have some effect on the level of presence reported on those days. For example, one participant mentioned, "If I have to remember to say ‘now’ it will break presence a little”. Indeed, the repeated measures ANOVAs on Attention Allocation and Self-Location did reveal significant effects of time, such that scores were higher on Day 1 than on Days 2 and 3 for each of those domains. It is possible that those differences were partially due to the break counter task, but it cannot be ruled out that there was a novelty effect since Day 1 was almost all participants’ first experience in VR. Also, the MEC-SPQ sub-domain scores were significantly higher than the mid-point on every sub-domain and on every day except for Suspension of Disbelief on Day 2. Thus, even if the break counter had an effect on Attention Allocation and Self-Location on Days 2 and 3, the effect did not appear to be strong enough to reduce presence into more neutral or low levels.

Some participants did express difficulty remembering to report breaks in presence. During the semi-structured interview, participants were asked if they found it difficult to remember to say the word “Now” when they experienced breaks in presence. Overall, 22 of the 49 participants responded “No” to this question, 11 responded “Yes”, and 16 had responses reflecting it was “A little” or “Sometimes” difficult to remember. When probed on this question, 16 of the 49 participants explicitly stated that “No”, they did not think there were any times when they forgot to say “Now” even if they experienced a break in presence. The remaining participants said “Yes”, “A couple of times”, “Probably” or something of that nature though anecdotally, the number times forgotten seemed to be relatively low. When asked to estimate how many times they forgot to say it, the highest number reported was “maybe a half dozen” over the course of the study.

Regarding the fairness of the break counter across age groups, it might have been expected that the aforementioned issue of it being a prospective memory task make it more difficult for older adults to remember than younger adults. Younger adults did report a significantly higher number of breaks in presence than older adults. Furthermore, more older adults (n=14) than younger adults (n=2) did not report any breaks in presence at all. However, results from the interview questions about the break counter did not seem to suggest that older adults had a more difficult time remembering to report them. Of the 22 participants who said it was not difficult to remember, 14 were older adults (See Figure 19). Additionally, 11 of the 16 participants who said they never forgot to report breaks in presence were older adults. Younger adults were mixed on if they felt it was difficult to remember to report breaks in presence, with 8 saying No, 3 saying Yes, and 13 saying a little bit or sometimes.

To further ascertain if reporting fewer breaks in presence was due to prospective memory failures, I examined the number of breaks in presence as determined by the retrospective presence slider (number of instances when scores were below -.1), which was not a prospective memory task (See Table 10). Of the 14 older adults that did not say the word "Now", 9 also did not have any breaks in presence on the slider, suggesting that for most of these participants, the lack of reporting breaks was not due to prospective memory failures. Both of the younger adults who did not say the word "Now" *did* have breaks in presence on the slider. Thus, although there were a few cases where there may have been prospective memory failures in reporting breaks (showed discrepancies between the break counter and the presence slider), it affected both younger and older adults.

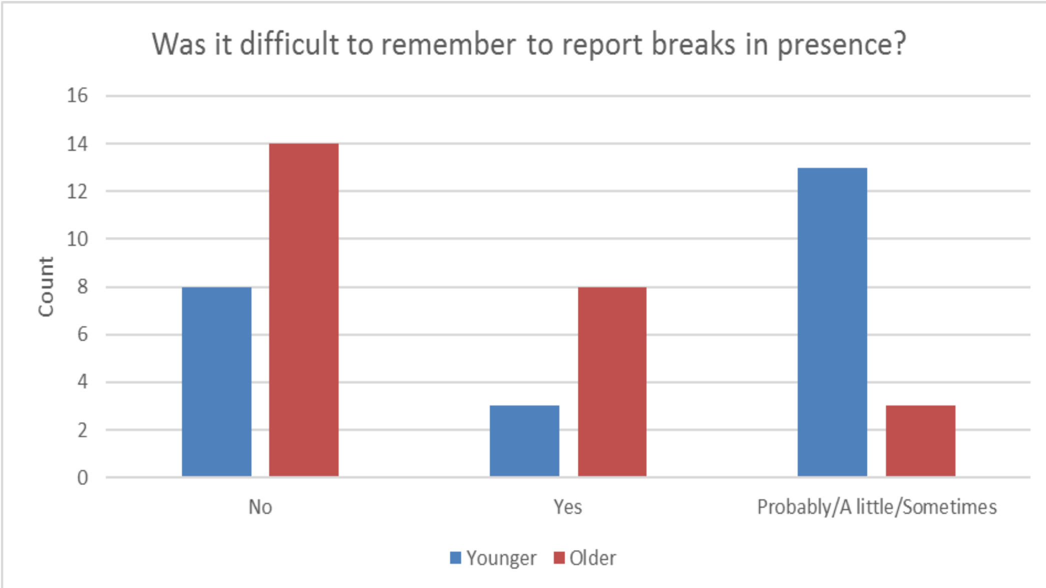


Figure 19. Perceived difficulty remembering to report breaks in presence.

Table 10

Zero Break Counter Breaks in Presence Reported vs. Presence Slider Breaks in Presence

Zero Breaks in Presence Reported (Counter)	# of Breaks in Presence (Slider)
Younger Adults	17
	9
Older Adults	23
	4
	2
	1
	1
	0
	0
	0
	0
	0
	0
	0
	0
	0

The next question regarding the validity of the break counter was to determine if it correlated with other validated presence measures (i.e., the MEC-SPQ) and with the other presence measures that were administered. Correlations were conducted between the break counter data and the MEC-SPQ sub-domains and between the break counter and presence slider data (means and % time virtually present). There were no significant correlations between the break counter and the MEC-SPQ or the presence slider means. However, number of breaks was significantly negatively correlated with the percentage of time spent virtually present as determined by the presence slider, such that individuals who reported more breaks in presence spent less time virtually present (r_s (49) = -.37, p = .009).

In sum, the findings regarding the validity and utility of the break counter are generally positive with some caveats. The main criticisms of this method are that it is inherently intrusive to the experience of presence because it introduces a secondary, prospective memory task that is irrelevant to the VR task. The results of this dissertation suggest that although the task of reporting breaks in presence may have a negative impact on certain components of presence, presence levels still remain high overall. Its usefulness may be limited for certain individuals that experience very few or no breaks in presence, and it can be expected that some individuals will forget to report breaks using this method some of the time. Encouragingly though, the evidence generally was not in favor of the break counter differences between younger and older adults being due to prospective memory failures or that the break counter task was disproportionally difficult for older adults compared to younger adults.

Retrospective Presence Slider

The break in presence counter method was developed to partially avoid the intrusiveness of doing a secondary task during the virtual experience (because it only needs to be done after presence is already broken). The traditional slider method cannot not avoid this limitation, as it is performed during the virtual experience itself. To avoid that limitation in this study, the presence slider was administered retrospectively by participants as they viewed a video of their active VR experience. Thus, it did not impact the experience of presence during the active VR session, but was still sensitive to temporal fluctuations in participants' presence.

The presence slider and semi-structured interview coincided with respect to presence formation for nearly all participants. 45 of the 49 participants experienced presence within the first 10 seconds of the session as determined by the presence slider. 42 of the 49 participants reported in the semi-structured interview that on average, after putting on the headset, they experienced presence immediately or within a few seconds.

Evidence of convergent validity between the presence slider and the MEC-SPQ was also observed for levels of presence. The presence slider means were significantly higher than the mid-point, as were the MEC-SPQ subdomains. Additionally, overall presence slider means correlated significantly with Day 2 Spatial Situation Model (r_s (49) = .33, p=.023) and Day 2 Self-Location (r_s (49) = .34, p=.019). These were both positive correlations, suggesting that people with higher presence slider means also reported higher spatial presence on these MEC-SPQ domains. The correlation with Self-

Location is particularly validating as the questions in that sub-domain reflect the core experience of presence (i.e., the feeling of 'being there').

However, comparing across groups, these correlations were only observed in the younger sample; Spatial Situation Model (r_s (25)= .48, p = .016), Self-Location (r_s (25) = .50, p = .01). Older adult presence slider means did not correlate significantly with any of the MEC-SPQ sub-domains. Thus, it is possible that the presence slider may be a better indicator of presence levels for younger adults.

As mentioned in the Maintenance of Presence section, there was also convergent validity regarding presence maintenance between the slider presence and the semi-structured interview. The percentage of seconds spent virtually present was high as determined by the presence slider (79.8%), which was similar to participants' verbal estimations of the total amount of time they spent virtually present (88.2%). Also of note is that some of the discrepancy between these two measures is due to a conservative treatment of the middle portion of the presence slider scale (between -.1 and .1), with 6.1% of the slider percentage data being indeterminant. Furthermore, the similarities in presence maintenance as measured by the slider and as determined by the semi-structured interview persisted across age groups (See Figure 15).

In addition to correlating with the break in presence counter, presence maintenance as determined by the slider (% virtually present) was significantly correlated with Spatial Situation Model (r_s = .30, p = .035) and Self-Location (r_s = .29, p = .043). Individuals that spent more time virtually present tended to report a greater sense of understanding the spatial layout of the virtual environment and having a greater sense of 'being there' in the virtual environment.

Again, these effects differed comparing across age groups. For younger adults, the correlations persisted between time spent virtual and Spatial Situation Model (r_s (25) = .57, p = .003) and between time spent virtual and Self-Location (r_s (25) = .41, p = .042). Older adults' time spent virtual no longer correlated with these two sub-domains, but did show a significant relationship with Possible Actions (r_s (24) = .46, p = .023).

In sum, convergent validity was observed between the presence slider and the semi-structured interview regarding presence formation. It was also observed between the presence slider and the post-experience questionnaires regarding overall level of presence (slider means) and overall presence maintenance (slider % time spent virtual). In these cases, one of the most persistent correlations was between the slider and Self-Location, which captures the most fundamental aspect of presence, the sensation of 'being there'. However, the relationships between these two slider presence metrics (means and % virtual) and the post-experience questionnaires differed when split across age groups. The slider-questionnaire relationships may have been primarily driven by younger adults, suggesting that the slider method used in this study may not be entirely appropriate for older adults. Yet, the reliability of the split group correlations is a concern given small group sizes (n=25) in addition to restriction of range in some of the MEC-SPQ sub-domains. Thus, the within group correlations should be interpreted with caution but can provide insights for future research.

Individual Differences in Spatial Presence

The final goal of this dissertation was to explore the potential that individual differences in the spatial presence process were related to and/or accounted for by certain cognitive abilities such as spatial ability, divided attention, focused attention, shifting attention, and executive control.

Because there were no hypotheses regarding the relationships between these abilities and presence on different days, MEC-SPQ sub-domain scores were aggregated across the three days of the study. Spearman's Rho correlations were conducted to explore the potential relationships between the ability measures and presence as measured by the MEC-SPQ sub-domains, slider presence, and breaks in presence (See Table 11 for a correlation table). For all ability measures except for Cube Comparison, scores were response times, such that higher scores were indicative of lower performance.

Attention Allocation correlated significantly with UFOV: Divided Attention, such that individuals with worse divided attention abilities tended to report devoting a higher degree of their attention to the virtual environment.

Spatial Situation Model correlated significantly with Cube Comparison and UFOV: Divided Attention, such that individuals with better spatial ability tended to agree more about being able to develop a spatial mental representation of the virtual environment and those with worse divided attention abilities agreed less about being able to develop a spatial mental representation of the virtual environment.

Self-Location correlated significantly with the difference in response times between correct incongruent and correct congruent trials on the Flanker task, such that individuals with worse executive control agreed less about being able to develop a spatial mental representation of the virtual environment.

Table 11

Spearman's Rho Correlations Between Ability Measures and Presence Measures

	Attention Allocation	Spatial Situation Model	Self-Location	Possible Actions	Cognitive Involvement	Suspension of Disbelief	Slider Presence	Breaks in Presence
Cube Comparison	-.20	.35*	.-.04	.41**	.02	.11	.14	.27
UFOV: Divided	.29*	-.31*	.11	-.40**	.00	-.05	-.05	-.43**
UFOV: Focused	.25	-.20	.11	-.38**	.07	.02	.02	-.42**
Stroop RT Difference (Correct)	-.04	-.16	-.02	.-.19	.09	.08	-.18	-.02
Flanker RT Difference (Correct)	-.10	.05	-.30*	.20	-.06	-.10	-.24	.21
TMT: Shifting	.22	-.22	.15	-.29*	.04	.10	-.05	-.21
TMT: Flexibility	.24	-.23	.18	-.29*	-.05	.04	-.15	-.16

*$p < 0.05$
**$p < 0.01$
Note: UFOV = Useful Field of View, RT = response time, TMT=Trail-Making Tests

Possible Actions correlated significantly with Cube Comparison, UFOV: Divided Attention, UFOV: Focused Attention, TMT: Shifting Attention, and TMT: Cognitive Flexibility. Individuals with better spatial ability, divided attention, focused attention, shifting attention, and executive control felt a higher degree of being able to interact with the objects in the virtual environment.

Regarding presence maintenance, individuals with lower divided and focused attention abilities tended to report fewer breaks in presence.

Cognitive Involvement, Suspension of Disbelief, and Slider Presence did not correlate significantly with any of the ability measures.

The further understand the role of ability measures in accounting for differences in spatial presence, multiple regression analyses were conducted on the MEC-SPQ subdomains. Because several of the ability assessments measured similar constructs, ability measures were grand mean centered and an exploratory Principal Components Analysis was conducted on UFOV: Divided Attention, UFOV: Focused Attention, Stroop RT Difference, Flanker RT Difference, TMT: Shifting Attention, and TMT: Cognitive Flexibility. UFOV: Divided Attention, UFOV: Focused Attention, TMT: Shifting Attention, and TMT: Cognitive Flexibility had the highest component loadings, so a composite score (hereto referred to as "Executive Control") was created with these variables.

The Cube Comparison Test and the Executive Control variable were used in the multiple regression models as predictors of the MEC-SPQ sub-domains. The resulting regression models were not significant predictors of the variance in any of the MEC-SPQ sub-domains except for Possible Actions (See Table 12). Overall, Cube Comparison and the Executive Control variable accounted for 15.1% of the variance in Possible Actions. However, neither Cube Comparison nor the Executive Control variable explained a significant unique amount of variance in Possible Actions and the amount of variance accounted for was minimal. Due to the relatively few number of significant correlations/predictions, and because of the small group sample sizes, within group analyses were not conducted for the ability measures (See Appendix G for a correlation table).

Table 12

Linear Regression Results for Possible Actions

Model	*B*	*SE*	*β*	*r*	*sr²*
Constant	4.30	.08			
Cube Comparison	.02	.01	.32	.382	.06
Executive Control	-.06	.11	-.10	-.303	.01
R^2	.15				
F	4.19*				

*p < .05. *B*=Unstandardized Beta. *SE* = Standard Error. *β* = Standardized Beta. *r* = zero-order correlation. sr^2 = squared semi-partial correlation.

CHAPTER 4: DISCUSSION

This dissertation was motivated by the continuously expanding number of domains in which VR has the potential to benefit physical, cognitive, and socio-emotional well-being for users of all ages. Virtual environments have been used in research aiming to improve second-language learning (Schwienhorst, 1998), aid in post-stroke motor rehabilitation (Sisto, Forrest, & Glendinning), neurosurgical training (Alaraj et al., 2011), space exploration (McGreevy, 1993), training soldiers (Baumann, 1993), identifying cognitive disorders (Cherniack, 2011) treatment of anxiety disorders (Meyerbröker, Emmelkamp, & anxiety), pain management (Sharar et al., 2008), remote tourism (Guttentag, 2010), improving communication in human-robot interaction (Milgram, Zhai, Drascic, & Grodski, 1993), product design (Ye, Badiyani, Raja, & Schlegel, 2007), fall reduction (Virk & McConville, 2006), and many others. The excitement and the effort to incorporate virtual technologies into different contexts is clear. Less clear is how effective virtual environments are at achieving the desired outcomes of these applications.

Spatial presence, the sensation of 'being there' in the virtual environment, has been shown to be paramount in facilitating the positive outcomes of virtual applications (Villani, Riva, & Riva, 2007). Because of this, there was a need to enhance our understanding of the spatial presence process in virtual reality while avoiding some of the limitations in the extant spatial presence literature.

The primary limitations in previous spatial presence research were:

1. Focusing on overall levels of presence

2. Focusing on the effect of immersiveness on presence
3. Samples (i.e., college students) vary little in potentially presence-relevant human factors

To address these limitations, this dissertation utilized different types of measures of presence that could capture components of the presence process that post-hoc questionnaires are not sensitive to (i.e., formation, maintenance, break recovery). Furthermore, the system was highly immersive and held constant throughout the study to increase the likelihood that presence occurred and to be able to investigate the human factors involved in the presence process. Older adults were included in the study as a proxy for age-related differences in presence-relevant abilities, of which, some specific abilities were measured. In doing so, we were able to begin to address the following research questions:

1. How long does it take for spatial presence formation to occur?
2. To what extent do people experience spatial presence?

2.1. To what extent do levels of presence change over time/with experience?

3. Once spatial presence is being experienced, how well do people maintain it?
4. If spatial presence is broken, how easy is it to regain?
5. How well do new and existing measurement methods capture the entire spatial presence process?
6. Do specific abilities account for differences in spatial presence?

Research questions 1-5 had an additional sub-question regarding age differences; are there age-related differences in presence formation, level, maintenance, break recovery, and measurement validity? These questions helped test specific components of the Magnet Model of Spatial Presence using new and existing measurement methods in a population with diverse characteristics and abilities.

There were several novel findings from this research that are informative to spatial presence theory, measurement, and future research on this concept. Specifically, presence formation occurred very quickly and people experienced high levels of presence (which persisted over time and for both age groups). Although, younger adults experienced more breaks in presence than older adults (possibly due to higher divided attention abilities), presence maintenance was high overall, such that people maintained presence in the virtual environment for the majority of the time spent in VR. People found it easy to recover when breaks in presence did occur, irrespective of age. Furthermore, there was convergent validity across the various types of presence measures implemented, which captured different components of the spatial presence process. Yet, there was limited evidence that individual differences in spatial presence were a result of differences in specific cognitive abilities. Additionally, we found that both younger and older adults enjoyed the experience and were highly engaged in the VR task. These results provide practical contributions to designers of VR systems, VR experiences, and applications of VR aimed at sustaining or improving cognitive, physical, and socio-emotional well-being for a broad range of potential users.

Engagement and Enjoyment in Immersive VR

Often, for certain types of interventions to be effective, it is essential for the person to enjoy and be engaged in whatever the task may be. For example, the benefits of physical activity interventions have been shown to depend on how enjoyable they are (Dishman et al., 2005 2005), and enjoyment can predict long-term adherence to such interventions (McAuley et al., 2007; Hu, 2007). This is likely to be the case for VR-based interventions as well. It is sometimes the case that the intervention is more enjoyable *because* it is in VR. In fact, presence has been shown to lead to greater enjoyment of an exercise intervention (IJsselsteijn et al., 2006 Jager, & Bonants, 2006). In this study, we found that both younger and older adults were highly engaged in the VR task consistently over the course of the study and enjoyed their experiences in general. This was of particular interest for the older adult group because of the relatively limited information we have regarding older adults' interactions with VR. That participants were engaged and continued to be engaged in this cognitive-perceptual-motor VR experience, provides evidence that these types of experiences can be used for VR training and interventions for people across a range of abilities.

The Spatial Presence Process

The Magnet Model of Spatial Presence builds off of the Wirth (2007), two-stage model of presence, which highlighted the roles of attention allocation and spatial mental model development as part of the first stage in the presence process. If people attend to the virtual environment and being to understand its spatial representation as they would a physical environment, they may begin to feel as though they are located in that virtual environment and have the ability to do things there.

Although many models of presence acknowledge that there is a part of the process in which presence formation occurs (Bystrom et al., 1999; Nunez, 2007; Regenbrecht, Schubert, & Friedmann, 1998; Wirth et al., 2007), the most common, and almost exclusively used method of measuring presence (post-experience questionnaires) is not conducive to understanding presence formation. Prior to this dissertation, it was unclear how long it took people to go through this presence formation process to first achieve the sense of presence in the virtual environment. In this study, almost all participants appeared to become virtually present very rapidly, even within the first few seconds of the VR session. One possibility, which is in line with what would be hypothesized in the MMSP, is that because the VR system was so immersive, the threshold for one's perceived self-location to cross over into the virtual environment was so low that presence formation was almost instantaneous.

Post-experience questionnaires do lend themselves to understanding overall level of presence, which is the most extensively studied component of the process. However, presence levels are sometimes assessed using a single item (Slater, Usoh, & Environments, 1993) or in non-immersive systems (Vorderer et al., 2004), in which it is debatable whether spatial presence can even occur. Other times, presence levels are assumed to be higher in conditions that use a more immersive system (Baumgartner et al., 2008), which may not necessarily be the case given that immersiveness has been shown to have only a moderate effect on presence (Cummings & Bailenson, 2016).

To be able to understand the effects of human factors on levels of presence, it is necessary to disentangle these from the effects of the system by controlling the level of immersiveness. Thus, it was critical in this research to hold the immersiveness of the system constant, to use a highly immersive system (one in which we could be confident that presence would occur), and to use theoretically-grounded presence questionnaires in addition to exploring levels of presence using novel methods. Indeed, another key finding from this dissertation was that people experienced high levels of presence in virtual reality. This was shown through the post-experience presence questionnaires, for which nearly every sub-domain on every day was significantly higher than the mid-point of those scales. The levels observed in this study were higher than what was observed in the development of the MEC-SPQ (Vorderer et al., 2004), likely due to their inclusion of non-immersive media. High levels of presence were also observed using the presence slider means, novel method of presence measurement.

Although high levels of presence in immersive VR were expected based on the literature, what was less well-understood was if levels of presence would persist over time. That is, one concern was that presence in VR could be somewhat of a novelty effect, such that as people continued to use VR and become familiar with the sensation, the feeling of presence would be diminished. If this were the case it would have serious implications for the use of VR as a tool for interventions or training because these types of applications (whether in VR or not) often require extensive repetition. Some evidence was observed for potential novelty effects. Specifically, Attention Allocation and Self-Location were higher on Day 1 than on Days 2 and 3. Suspension of Disbelief was higher on Day 3 than on Day 2. Higher Day 3 Suspension is Disbelief is somewhat counter-intuitive in conjunction with the lower Day 3 Self-Location finding; if people were more likely to suspend disbelief on Day 3 (i.e., focus less on inconsistencies in the virtual environment), I would have expected them to feel *more* as though they were located in the virtual environment. It is a bit easier to reconcile with the lower Day 3 Attention Allocation finding; perhaps their lack of focus on virtual inconsistencies was because they were also devoting less attention in general to the virtual environment.

Yet, these potential novelty effects were not widespread across all presence sub-domains and there are a number of reasons other than novelty for Day 1 being the highest. Participants needed to report breaks in presence on Days 2 and 3, which could have had a negative influence on their levels of presence. It is noteworthy that even though Day 1 was higher on some of the domains, it was still very high, suggesting that whatever caused different levels on different days did not impact presence to the extent that the sensation became neutral or weak overall. Although some VR interventions are likely to last longer than the duration that participation in this study required, these findings provide evidence that high levels of spatial presence in immersive VR do not diminish rapidly as people spend more time and gain more experience with the system. This finding, in conjunction with observations that immersive VR tends to result in more enjoyment compared to non-immersive VR (IJsselsteijn et al., 2006) suggests that immersive VR should be used to maximize the effectiveness of VR applications.

The largest contribution of this dissertation was in providing insights regarding maintenance of presence through usage of existing and novel measures of presence that were sensitive to within-experience fluctuations. Overall, people felt virtually present for the majority of the time spent in VR, as indicated by both the presence slider and the semi-structured interview. Additionally, on average, people reported only 2.8 breaks in presence during the 10-minute session. This was slightly lower than what has been previously reported, possibly due to the inclusion of older adults. Slater & Steed (2000) observed an average of 3.6 breaks in presence in a study with only 16 younger participants and for an approximately 5-minute session. Because that was not a recent study, it is also likely that the system used (though it was a head-mounted display) was not as immersive as the one used in this study, which could be another reason why more breaks in presence were reported.

The quality of VR systems are improving rapidly, but even higher-end headsets are still far from perfect; most are heavy, wired, and have subpar visual quality (i.e., perceptible pixels). During a VR experience these types of system-related attributes, as well as other factors (e.g., noise, mind-wandering) can pull users' focus away from the virtual environment and cause a break in presence. For people such as interventionists, researchers, and VR system designers, it is essential to consider just how impactful breaks in presence can be to the overall experience so informed decisions regarding VR system/experience selection and design can be made. This dissertation addressed the question of the intrusiveness of breaks in presence. That is, when breaks in presence occur, how easy or difficult is it to regain a sense of virtual presence after presence is broken?

A novel method of experimentally inducing breaks in presence was developed for this study, where a digital overlay of the physical environment was projected into the headset two times over the course of the 10-minute session on one of the study days. Almost all of the participants indicated that they saw their physical environment during the induced break. For slightly fewer people (though still most of the participants overall) this induced break was effective, indicating that when it occurred, they felt more physically present. Of these individuals, almost all said that it was easy to recover from these breaks in presence.

Unfortunately, there was evidence that other measures that were developed for this study to assess recovery from breaks in presence were not reliable. For example, one of the response options to the Break Susceptibility and Recovery Questionnaire was "N/A: I did not experience a break in presence" and some individuals chose that option for some of the questions but not others. If they did not experience a break in presence, they should have chosen that option for all of the items. Additionally, I anticipated the break slider to be able to capture the number of seconds it took for people to recover from the induced breaks. However, the exact inception and length of the induced breaks was not specific enough to be able to calculate this with a high degree of reliability. With future iterations of these measures, they have the potential to be effective assessments of break recovery time. However, because there was evidence of rapid presence formation and high presence maintenance overall, I think it is safe to conclude that the interview responses suggesting quick break recovery time were valid.

Age and the Spatial Presence Process

There were several motivations for including older adults in this research. VR has a plethora of applications that can benefit older adults (Cherniack, 2011; Hodges et al., 1995; Hoffman et al., 2004; Molina et al., 2014; Satava, 1995; Schultheis & Rizzo, 2001; Sisto et al., 2002; Wilson, Foreman, & Stanton, 1997) and we know that the effectiveness of various VR applications tends to increase when users experience spatial presence. There are a variety of cognitive and perceptual changes that occur with age that were expected to have an impact on the spatial presence process (McGlynn, Sundaresan, & Rogers, 2018), yet older adults are often not included in spatial presence research or VR system design. This limits the potential for VR applications and limits the generalizability of theoretical spatial presence models across a range of user types.

This research resulted in a few key findings regarding age and spatial presence in VR. Despite the fact that there tend to be age-related differences in perceptual (Cavanaugh & Blanchard-Fields, 2014) and cognitive abilities (Craik & Byrd, 1982;

Verhaeghen, & Cerella, 2002), these changes generally did not appear to have a significant influence on the different components of the spatial presence process.

It was hypothesized that presence formation might occur more slowly for older adults, perhaps due to declines in perceptual abilities, focused attention, and response inhibition. This might make them less able to devote attention to the virtual environment, develop a spatial situation model of the environment, and inhibit stimuli from the physical environment. Yet, the evidence suggested presence formation occurred very quickly for all participants. One possibility is that the physical environment was so imperceptible and the virtual environment so attention-grabbing due to the immersiveness of the system, that these types of abilities became less relevant to the presence formation process. It may also have been the case that even if these abilities did play a role, age-related declines could have facilitated the presence formation process, such that limitations of the VR system that could slow the process (e.g., awareness of the screen pixels) might have been less noticeable for older adults.

One caveat with the presence slider method of assessing presence formation (i.e., most participants became present within 10 seconds of the experience) was that the retrospective presence slider session began in the video at the beginning of the Diner Duo session, not right when the participant put the headset on (to keep the total slider times consistent; some people took longer to get the experience started with most participants). As such, it could have been the case that on the slider, virtual presence appeared to be so immediate because participants knew that they had already been experiencing presence during the minute or so that it took them to get the experience started. Nonetheless, becoming present before the experience even started would still indicate that presence formation occurred quickly and the semi-structured interview supported this finding as well.

Though levels of presence have been studied extensively, the relationship between presence levels and age has not been, with the two studies exploring this relationship and finding conflicting evidence. (Bangay & Preston, 1998) observed a negative relationship between presence and age and (Schuemie et al., 2005) observed a positive relationship. Yet, these studies were limited in the presence measurement method used and in the range of ages in their samples. So although potential patterns of presence for younger vs. older adults were hypothesized, it was unclear if a relationship would be observed and what the nature of that relationship would be.

In this study, there was little evidence to suggest that levels of presence differed across age groups. Age differences were only observed in two of the MEC-SPQ sub-domains; Attention Allocation and Possible Actions. Older adults reported devoting more attention to the virtual environment than younger adults overall. Younger adults reported a greater sense of action possibilities within the virtual environment than older adults. Although as much training was provided as possible in the time allotted and older adults were generally able to pick up on the active VR task, VR is still a very advanced technology. Given cohort differences in technology familiarity as well as changes in cognitive and physical abilities, it is not surprising that older adults devoted more attention to the virtual environment than younger adults; the virtual task likely required them to. For similar reasons, it makes sense that younger adults perceived greater action possibilities within the virtual environment given that they were able to complete that task much faster (e.g., complete more burgers per session). They may have felt greater action possibilities within the environment because they had opportunities to interact successfully with a greater number of objects. However, although these age differences were observed, both age groups still experienced high levels of presence. Slider means were significantly higher than the midpoint for both groups, as were MEC-SPQ scores on every day for every sub-domain with the exception of Suspension of Disbelief. Because older adults can experience high levels of presence in immersive VR, it follows that it is possible (and likely) that they will experience the benefits of VR applications.

It was hypothesized that younger adults would experience lower presence maintenance than older adults. One of the key findings from this research was in support of this hypothesis. Younger adults reported significantly more breaks in presence than older adults. Many older adults did not report any breaks in presence whatsoever. It is possible that this was due to age-related differences in divided attention abilities. That is, once presence formation had occurred, younger adults might have been more easily able to split their focus and alternate their sense of being across the virtual and physical environment throughout the experience, resulting in more breaks in presence.

This finding was corroborated by age differences in level of presence for Attention Allocation. Older adults reported devoting more attention to the virtual environment than younger adults, which may have resulted in fewer breaks in presence. Another explanation for more younger adult breaks in presence makes sense in the context of age differences in Action Possibilities. Younger adults, who performed the task more quickly than older adults (i.e., more burgers), had more opportunities for action possibilities within the virtual environment, which may have resulted in more opportunities for breaks in presence. Anecdotally, when asked what caused breaks in presence, many of the causes were related to inconsistencies in the virtual environment (i.e., virtual hand passing through the counter, objects not acting as they would in the physical environment). Thus, the likelihood of inconsistencies occurring increased as younger adults completed more burgers.

However, more breaks in presence did not result in a significant reduction in the amount of time spent virtually present. Both age groups had similar presence slider (% virtual seconds) and semi-structured interview responses (estimated % time virtual). The likely explanation is that presence formation and break recovery occurred so quickly that the total percentages of time spent virtual were similar across age groups in spite of younger adults reporting more breaks in presence. Crucially, age differences in presence maintenance as measured by the break in presence counter did not appear to be due to prospective memory failures, which would have been expected to be more prevalent in older adults than in than younger adults. Most participants did not find it difficult to remember to report breaks in presence. Also, the majority of older participants who did not report any breaks in presence also did not show breaks in presence on the presence slider (which was not a prospective memory task).

A break in presence is essentially a shift in attention from the virtual to the physical environment that results in you returning to feeling as though you are 'there' in the physical environment. It was hypothesized that older adults might have a more difficult time recovering from breaks in presence due to differences in shifting attention abilities. Although the only assessment of recovery from breaks in presence was a semi-structured interview question, the evidence did not support this hypothesis. Most participants reported recovering quickly from breaks in presence.

In sum, there was little evidence to suggest that younger and older adults differ in presence formation, level, or recovery from breaks in presence. Older adults devoted more attention to the virtual environment and younger adults perceived more action possibilities in the virtual environment. Overall, both age groups maintained presence in the virtual environment for the majority of the time spent in VR. However, younger adults' virtual presence was broken more frequently than younger adults, perhaps due to having more opportunities for breaks in presence to occur and being better able to divide their attention across the virtual and physical environment. These results provide evidence that in immersive VR, users experience spatial presence rapidly, consistently, and to a high degree. Because experiencing spatial presence is critical for VR applications, it is likely that these applications will be effective for users of varying characteristics and abilities.

Individual Differences in the Spatial Presence Process

Previous models of spatial presence have emphasized the importance of attention allocation in the experience of presence. Draper, Kaber, and Usher (1998), defined presence as a state that arises when a technology user commits her/his attentional resources to the technology-mediated world and inhibits perception of sensory information coming from the physical world. In this dissertation, I aimed to advance our understanding of the relationship between attention and presence by investigating the extent that sub-types of attention related to spatial presence in immersive VR and using age as a proxy for changes in attention. I hypothesized that the presence formation process would be faster for individuals with better focused attention and response inhibition, that presence maintenance would be lower for individuals with better divided attention, and that recovery from breaks in presence would be faster for individuals with better focused attention, higher response inhibition, and higher shifting attention. These were reflected in measures of these abilities and by using age as a proxy for cognitive changes.

In general, there was little evidence suggesting that individual differences in spatial presence levels were predicted by the cognitive abilities measured in this study. There was evidence in support of the hypothesized relationship between divided attention and presence maintenance. Specifically, I expected that individuals with higher divided attention ability would be better able to allocate attention to the virtual and physical environments simultaneously, and as a result they would have lower presence maintenance. Indeed, individuals with higher divided attention abilities reported allocating less attention to the virtual environment and also reported more breaks in presence. These types of relationships could be informative for selecting individuals for VR training or intervention applications.

The most consistent relationship between abilities and levels of presence was with Possible Actions. Individuals with better spatial ability, divided attention, focused attention, shifting attention, and cognitive flexibility, tended to feel a greater sense of being able to interact with objects in the virtual environment. Indeed, executive control (composite measure) and spatial ability predicted a significant amount of variance in Possible Actions, though the effect size was small and the ability variables did not uniquely account for a significant amount of variance. No other MEC-SPQ sub-domains were predicted using this model.

Presence formation and recovery from breaks in presence appeared to occur almost rapidly for nearly all participants, limiting the extent that these could have been predicted by specific cognitive abilities. Additionally, in general there were few significant correlations or predictions observed, and many of those that were observed were not hypothesized or anticipated. Thus, we decided not to attempt to move forward with age group comparisons in ability measures, especially given the small group sample sizes. Although the individual differences analyses were somewhat exploratory, the correlations that were observed, particularly the relationship between divided attention and breaks in presence, can provide a foundation for future research on the effect of specific abilities on the different components of the spatial presence process.

Spatial Presence Measurement

Post-experience questionnaires certainly have advantages; face validity, some are grounded in theory, they are often sensitive to varying degrees of immersiveness, and can be diagnostic if they incorporate the multidimensionality of presence. They are limited, however, in a way that most post-task questionnaires are, they require the user to remember how they were feeling after the fact. This may be acceptable for certain types of judgements/experiences (i.e., confidence, stress) but given the novelty of the concept of spatial presence and the fact that people likely never consider their level of spatial presence in everyday life, they may not be the best (or at least, most complete) way of understanding spatial presence. Furthermore, they tend to focus primarily on the overall level of presence. This limited our understanding of how quickly people become present, how to keep people 'there' once they become present, and how they recover when presence is broken. Understanding such nuance in the spatial presence process is informative for spatial presence theory, future research, and the design of effective VR applications.

As such, it was essential to better understand temporal fluctuations in presence using and/or creating tools that are capable of capturing these within-experience changes. The break counter and presence slider methods are sensitive to such fluctuations. Additionally, qualitative research has been underutilized in the spatial presence literature, but has the ability to provide support to other methods and also provide insights that are difficult to otherwise ascertain.

The benefit of the break counter method is that it is thought to be relatively unobtrusive to the experience of presence itself because users only need to say the word "Now" once presence has already been broken. This study provided evidence both in favor of and against using the break counter method. Some of the MEC-SPQ sub-domains were lower on Days 2 and 3 than on Day 1, which may be because the break counter task was intrusive to presence, yet, those sub-domains still remained high on all days.

The break in presence counter did not correlate significantly with any of the MEC-SPQ sub-domains. However, it was negatively related to presence maintenance as measured by the slider, such that those who reported more breaks in presence tended to spend less time virtually present overall.

Close to half of the participants explicitly stated that remembering to report breaks in presence was not difficult. Others said that yes it was somewhat difficult at times, but even those participants felt that there were only a few times when they forgot to say it. So, the evidence seems to suggest that if it did impact presence, the effect was minimal. The break counter method also seemed to be somewhat appropriate for use by younger and older adults. There was concern that reporting breaks in presence during the experience (a prospective memory task), would be more difficult for older adults to remember to do than younger adults. The evidence did not suggest that this was the case. Even though older adults reported significantly fewer breaks in presence, the majority felt that it was because they did not experience them, not because they forgot to report them. However, this does not entirely rule out the possibility that there were prospective memory failures, as older adults are sometimes inaccurate in self-assessments of their memory abilities (Dobbs & Rule, 1987). Future research using the break counter should also administer an assessment of prospective memory to determine.

For these reasons, the break counter method should be implemented with caution as there was some evidence that it may have impacted the experience of presence (though to a small degree). If used, it should also be expected that people will forget to say "Now" several times. However, one benefit of using the break counter method can be if the goal is to identify instances that people felt *caused* breaks in presence rather than using it to assess presence itself. In the original development of the break counter method, Slater & Steed (2000) found that the causes of breaks in presence could be classified into two main types; internal and external. Internal breaks were defined as something “wrong” with the virtual world itself, such as the laws of physics not being obeyed, objects looking unreal, or display lag. External breaks were defined as sensory information from the real world that intruded into or contradicted the virtual world such as people talking or the touch/feel of physical objects. Though causes of breaks in presence was not the focus of this study, participants were asked to try to remember what caused their break in presence. Similar classifications of break causes were observed. For example, several of the participants in this study mentioned that their presence was broken when “things aren’t acting the way you think they should” (internal), such as if they tried to lean on the virtual countertop and nothing was there, or when they looked down and saw they didn’t have a body. Others mentioned external breaks in presence, such as “hitting my elbows on the chair” or “seeing light [from the physical environment] through the sides of the headset”. Additionally, some participants mentioned experiment-related breaks in presence, such as “having to do the “Now” thing” and “wanting to tell you [the experimenter] things”. These types of insights can be useful to designers of VR experiences and systems in addition to being useful to people who are attempting create VR setups for the aforementioned applications of VR. As such, the reported causes of breaks in presence observed in this study may be coded and analyzed thematically analyzed in future work.

The presence slider method was developed by IJsselsteijn et al. (1998) as a method for determining if there were within-experience fluctuations in presence in response to image content and camera techniques used in a 3D movie. They concluded that presence was subject to temporal fluctuations, but the measure was criticized for being intrusive to the experience of presence. The retrospective version of the presence slider method was developed for this study to allow it to be used without interfering with the experience of presence. In doing so, it faced some of the same limitations as post-experience questionnaires because it required people to remember a previous experience. However, this memory challenge was lessened by the fact that respondents were simultaneously viewing the videos (from the viewpoint of their own eyes, so to speak) of their VR experiences. The advantage of this method over post-experience questionnaires is that it can capture within-experience fluctuations in presence; it is essentially as if you were to administer a single presence question (i.e., "Do you feel more virtually present or physically present?") during each moment in the experience.

For the most part, this study provided evidence in support of the retrospective presence slider method. It mirrored findings from the post-experience questionnaires in that slider presence was significantly higher than the midpoint overall and for both age groups. Additionally, the presence slider patterns coincided with the semi-structured interview responses in terms of the short length it took to initially become present and the high percentage of time that participants spent virtually present over the course of the sessions.

The presence slider also correlated positively with Spatial Situation Model and Self-Location. This is noteworthy because the presence slider can effectively be thought of as a single presence questionnaire item that was responded to at every moment in the experience. Thus, the finding that it correlated with Self-Location spatial presence sub-domains provides some evidence for specificity in the retrospective presence slider method. Comparing across groups, these correlations were only significant in the younger sample, suggesting that this measurement method may be a better indicator of presence levels for younger adults than older adults. However, with small group sample sizes, the within group correlations or lack thereof may not be meaningful.

One caveat with the retrospective presence slider technique developed for this study is that the participants could hear themselves saying the word "Now" (from the break counter method) as they were viewing the videos of their sessions. It was done in this manner so the videos would depict participants' sessions as accurately as possible and as a result, the data would best represent how participants' responses would be if it was conducted in-VR. Because it was done this way, the relationship between the presence slider and the break should be interpreted with caution since a break in presence would almost necessarily cause a decrease on the slider. However, the main goal of using this method was for it to assess within-experience presence and to compare it to post-experience questionnaires, not to the break counter. It would be informative for future research to implement the retrospective presence slider and break counter but to not use the headset microphone to record participants' verbalizations. Analyzing the extent that breaks using the counter method coincide with breaks using the presence slider would be a good way to validate these methods.

Overall, the retrospective presence slider appears to be a valid assessment of presence. However, the exact implementation of it in this study may not have been the most appropriate method. The touchpad of the Vive controller was used as the input method as a way to avoid participants from learning an entirely new input method for this portion of the study. This made it difficult to determine if small fluctuations in slider presence were meaningful (i.e., was a .1 change due to a change in presence or unintentional finger movement). This likely had some effect on both groups, but possibly more so for older adults whom presumably have less experience using touch inputs, which is why presence slider scores were adjusted to include "indeterminant" (between -.1 and .1) and some of variables used in analyses used these data as binary (greater than .1=virtual, less than -.1=physical). This input method may also have been the reason why it did not correlate with the MEC-SPQ for older adults. Future studies should implement a similar slider method but with a more physical input such as a sliding bar or joystick.

Limitations and Future Directions

There are several limitations and avenues for future research in addition to those previously discussed. One is that although holding the immersiveness constant and at a high level, these findings are not generalizable to other types of systems. What would be predicted in the MMSP is that the system immersiveness determines the threshold between the physical and virtual environment, with the threshold becoming lower as the system increases in immersiveness. The results of this study suggest that this may have been the case, such that it compressed the amount of time needed for presence formation to occur as well as the amount of time that it took to recover from breaks in presence. It is possible that age-related differences would have been observed in less immersive systems. It would also be feasible to run this study using the same active VR task and system but to decrease the immersiveness by removing the audio or only allowing participants to use one controller, which could be done in future research. Doing so would likely introduce more variance and increase the range in presence levels as determined by the MEC-SPQ, which was exhibiting some ceiling effects and restriction of range effects on some of the sub-domains. However, I think it is important to the study of spatial presence to use the most highly immersive system possible, since the systems that are currently highly immersive are likely to be low-end systems in the near future. Instead, it may be more important to modify presence questionnaires so that responses are observed across the full range of the scale in immersive systems.

Another limitation related to the system/setup in this research is that the experience was purposefully performed sitting down. This was done for safety purposes as well as to limit the extent that participants would become fatigued (and likely at different rates for younger vs. older adults). Some applications of VR (e.g., balance/gait training) cannot be done sitting down. Different patterns of presence may have been observed had participants been standing or walking, which should be explored in future work.

These findings also cannot be generalized across different virtual experiences. Though the experience was selected to engage cognitive, perceptual, and motor abilities similar to those engaged in many of the applications of VR for training and therapy, not all of the applications of VR are able, nor need to engage these abilities. For example, VR has been used as a tool for relaxation, the purpose of which is not to engage these types of abilities. Thus, it is unclear if people will experience presence as quickly, consistently, or to the same extent that they did in this study.

Furthermore, the graphics in the active VR experience were cartoonish, and so it is unclear if similar results would have been observed if the environment were more photorealistic. For certain types of VR applications such as surgical training, part of the effectiveness of VR as a training tool (i.e., transfer of training from the VR environment to the operational environment) might *depend* on the experience being photorealistic. Anecdotally, a few participants mentioned that they felt more present in the passive VR experience because it was more realistic than the active VR experience. Yet, for applications that do not depend on photorealism, it is promising that levels of presence were as high as they were in this study. They may have even been high for some people *because* the experience was not photorealistic. Perhaps because the physical environment is (clearly) photorealistic, having a cartoonish virtual environment limits the extent that people notice inconsistencies because they do not have as many preconceptions about what it is like to be in a cartoon world. Creating photorealistic VR environments is likely to be more expensive in terms of time to create and computational power, so if it is not necessary for the experience to be photorealistic, reduced realism will probably be sufficient.

Another limitation of this research is that although one of the key findings was that levels of presence tended to persist over the course of the study, it still did not take place over an extensive period of time. Many VR applications (e.g., physical therapy) require much longer than the 3-10 days that this study took place in. It is possible that over longer periods, levels of presence would diminish with time/experience. Future research should explore levels of presence (and possible age-differences) with a more longitudinal approach.

Although a major contribution of this research was the inclusion of older adults, it is possible that the lack of age-related differences may have been because the underlying mechanisms involved in experience of spatial presence differed for younger and older adults. That is, presence may have been high across age groups for different reasons. Future research should consider including a more continuous range of ages rather than an extreme groups approach.

In addition to the measurement issues discussed previously, the presence slider (as it was administered in this study) is essentially collection of moment-to-moment responses to a single presence question (i.e. where did you feel more present?). As such, it faces similar issues as single-item assessments. Yet, in future research, the method could be modified to have participants repeat the video viewing session but with different instructions. The presence slider could be administered separate times for each of the four Self-Location questions or it could be administered separately for each of the MEC-SPQ sub-domains (e.g., indicate where you were allocating your attention at each moment in the experience), which would allow it to capture the multidimensionality of spatial presence.

Another measurement issue is that although an important contribution of this research was the incorporation of multiple presence measurement methods (some of which were sensitive to within-experience fluctuations in presence), they were still all subjective measures. Despite a lack of evidence that objective measures (e.g., skin conduction, heart rate) are valid assessments of presence, it would still be informative to include such measures in future research. In fact, one way to help validate objective measures would be to administer them during the VR experience and explore the correlation between the patterns of fluctuation based on these measures and the patterns observed using the retrospective presence slider.

In sum, many of the limitations of this research were methodological decisions that enabled investigation of the primary research questions. Yet, these limit the generalizability of some of the study findings and should be avoided or controlled for in future studies.

Conclusions

This dissertation explicitly tested components of the MMSP. See Figure 20 for a simplified version of this model that includes how the major findings of this research informed different components of the spatial presence process.

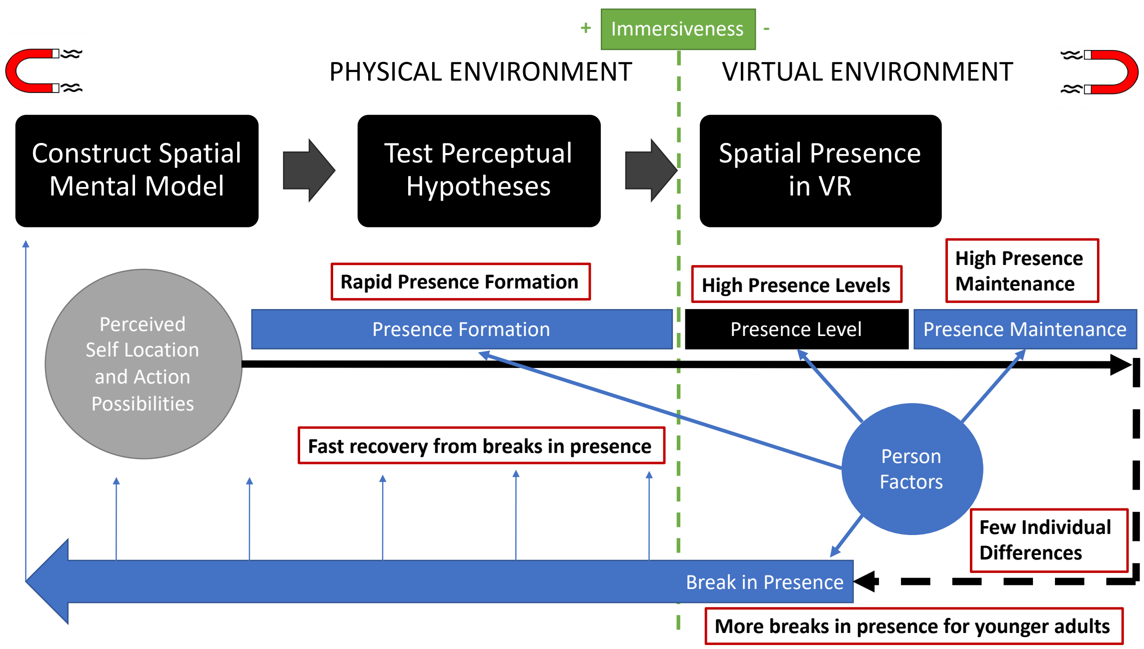


Figure 20. Mini-magnet model of spatial presence with the key findings (red boxes) of this dissertation.

Using a highly immersive system, using age as a proxy for changes in presence-relevant abilities, and measuring presence-relevant abilities, this research provided insights on different components of the spatial presence process through multiple methods. Presence formation occurred very rapidly (likely because the immersiveness of the system reduced the length required for formation to occur), presence levels were high, and presence maintenance was high. Though younger adults experienced more breaks in presence, recovery from breaks in presence was fast. In addition to minimal age-related differences in general, there was little evidence that individual differences in presence-relevant abilities predicted differences in the various components of the spatial presence process.

These findings led to the following insights and recommendations regarding VR systems/experiences and measures of presence:

- Virtual Reality System/Experience Insights and Recommendations
    - Immersive VR elicits high levels of presence across a range of users
    - Levels of presence persist over time (short periods) and with VR experience
    - Non-photorealistic experiences can elicit high levels of presence
    - Qualities of the system (e.g., wires) and experience setup (e.g., physical objects) can cause breaks in presence
    - Inconsistencies in the virtual environment (e.g., physical objects passing through each other) can cause breaks in presence
- Presence Measurement Insights and Recommendations
    - Questionnaires capture levels of presence, are unobtrusive and are appropriate across age groups – useful if temporal fluctuations in presence are not of interest

- Questionnaires show some ceiling effects/restriction of range in immersive VR - information derived from presence questionnaires may be limited when using highly immersive systems
- Break in presence counters capture extreme drops in presence but do not necessarily reflect overall presence maintenance
- Break in presence counters are relatively unobtrusive but people may forget to report them some of the time
- Some people will not experience any breaks in presence (possible age effects)
- Break in presence counters should only be used in conjunction with other methods, but can be an effective method for probing causes of presence breaks
- Presence sliders are valid to administer retrospectively and are unobtrusive using this method of administration (though some input modifications may be necessary for them to be appropriate for older adults)
- If multi-dimensionality is not of interest, presence sliders are the single best method for capturing the entire spatial presence process.

These insights and recommendations are valuable insights for researchers, interventionists, and designers of VR systems and experiences. This dissertation also provided substantial knowledge to the theory of spatial presence, specifically, toward expanding models of spatial presence beyond levels and broadening our understanding of the role of the human user in the presence process. VR has exciting potential applications in a seemingly endless number of contexts. This dissertation has helped increase the likelihood that when used in these contexts, the benefits of VR will be achieved to the greatest extent possible across a wide spectrum of potential users.

APPENDIX A: POST-EXPERIENCE QUESTIONNAIRES

MEC-SPQ (4)

The following are statements about the virtual reality experience you just participated in. Indicate the extent to which you agree or disagree with these statements by selecting the appropriate response. The response options are as follows:
1) Strongly Disagree
2) Disagree
3) Neutral
4) Agree
5) Strongly Agree

Indicate the extent to which you agree or disagree with the following statements

	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)
1) I devoted my whole attention to the virtual experience	○	○	○	○	○
2) I concentrated on the virtual experience	○	○	○	○	○
3) The virtual environment captured my senses	○	○	○	○	○
4) I dedicated myself completely to the virtual environment	○	○	○	○	○

Indicate the extent to which you agree or disagree with the following statements

	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)
5) I was able to imagine the arrangement of the spaces presented in the virtual environment very well	○	○	○	○	○
6) I had a precise idea of the spatial surroundings presented in the virtual environment	○	○	○	○	○
7) I was able to make a good estimate of the size of the virtual environment	○	○	○	○	○
8) Even now, I still have a concrete mental image of the spatial environment	○	○	○	○	○

Indicate the extent to which you agree or disagree with the following statements

	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)
9) I felt like I was actually there in the virtual environment	○	○	○	○	○
10) It was as though my true location had shifted into the virtual environment	○	○	○	○	○
11) I felt as though I was physically present in the virtual environment	○	○	○	○	○
12) It seemed as though I actually took part in the action of the virtual environment	○	○	○	○	○

Indicate the extent to which you agree or disagree with the following statements

	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)
13) I had the impression that I could be active in the virtual environment	○	○	○	○	○
14) I felt like I could move around among the objects in the virtual environment	○	○	○	○	○
15) The objects in the virtual environment gave me the feeling that I could do things with them	○	○	○	○	○
16) It seemed to me that I could do whatever I wanted in the virtual environment	○	○	○	○	○

Indicate the extent to which you agree or disagree with the following statements

	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)
17) I thought most about things having to do with the virtual environment	○	○	○	○	○
18) I thoroughly considered what the things in the virtual environment had to do with one another	○	○	○	○	○
19) The virtual environment activated my thinking	○	○	○	○	○
20) I thought about whether the virtual environment could be of use to me	○	○	○	○	○

Indicate the extent to which you agree or disagree with the following statements

	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)
21) I concentrated on whether there were any inconsistencies in the virtual environment	○	○	○	○	○
22) I didn't really pay attention to the existence of errors or inconsistencies in the virtual environment	○	○	○	○	○
23) I took a critical viewpoint of the virtual environment	○	○	○	○	○
24) It was not important to me whether the virtual environment contained errors or contradictions	○	○	○	○	○

Indicate the extent to which you agree or disagree with the following statements

	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)
25) I am generally interested in the topic of the virtual environment	○	○	○	○	○
26) I have felt a strong affinity to the theme of the virtual environment for a long time	○	○	○	○	○
27) There was already a fondness in me for the topic of the virtual environment before I was exposed to it	○	○	○	○	○
28) I just love to think about the topic of the virtual environment	○	○	○	○	○

Igroup Presence Questionnaire

Rate the extent that you agree with the following statements. Note that the response options are not the same for every question.

In the computer generated world I had a sense of "being there"

- Strongly Disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly Agree (5)

Somehow I felt that the virtual world surrounded me

- Strongly Disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly Agree (5)

I felt like I was just perceiving pictures

- Strongly Disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly Agree (5)

I did not feel present in the virtual space

- Strongly Disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly Agree (5)

I had a sense of acting in the virtual space, rather than operating something from outside

- Strongly Disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly Agree (5)

I was aware of the real world surrounding while navigating in the virtual world (i.e., sounds, room temperature, other people, etc.)

- Strongly Disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly Agree (5)

I was not aware of my real environment

- Strongly Disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly Agree (5)

I still paid attention to the real environment

- Strongly Disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly Agree (5)

I was completely captivated by the virtual world

- Strongly Disagree (1)
- Disagree (2)
- Neutral (3)
- Agree (4)
- Strongly Agree (5)

How much did your experience in the virtual environment seem consistent with your real world experience?

- ◯ Not consistent (1)
- ◯ (2)
- ◯ Moderately consistent (3)
- ◯ (4)
- ◯ Very consistent (5)

The virtual world seemed more realistic than the real world

- ◯ Strongly Disagree (1)
- ◯ Disagree (2)
- ◯ Neutral (3)
- ◯ Agree (4)
- ◯ Strongly Agree (5)

How real did the virtual world seem to you?

- ◯ About as real as an imagined world (1)
- ◯ (2)
- ◯ Neutral (3)
- ◯ (4)
- ◯ Indistinguishable from the real world (5)

Simulator Sickness Questionnaire
Select how much each symptom below is affecting you right now

	None	Slight	Moderate	Severe
General discomfort	○	○	○	○
Fatigue	○	○	○	○
Headache	○	○	○	○
Eye strain	○	○	○	○
Difficulty focusing	○	○	○	○
Salivation increasing	○	○	○	○
Sweating	○	○	○	○
Nausea	○	○	○	○
Difficulty concentrating	○	○	○	○
Fullness of the head	○	○	○	○
Blurred vision	○	○	○	○
Dizziness with eyes open	○	○	○	○
Dizziness with eyes closed	○	○	○	○
Vertigo (loss of orientation)	○	○	○	○
Stomach awareness (discomfort just short of nausea)	○	○	○	○

NASA-TLX

Mental Demand: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Very Low Very High

0 5 101520253035404550556065707580859095100

Mental Demand	

Physical Demand: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Very Low Very High

0 5 101520253035404550556065707580859095100

Physical Demand	

Temporal Demand: How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Very Low Very High

0 5 101520253035404550556065707580859095100

Temporal Demand	

Performance: How successful were you in accomplishing what you were asked to do?

Perfect Failure

0 5 101520253035404550556065707580859095100

Performance	

Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Very Low Very High

0 5 101520253035404550556065707580859095100

Effort	

Frustration: How insecure, discouraged, irritated, stressed, and annoyed were you?

Very Low Very High

0 5 101520253035404550556065707580859095100

Frustration	

End of Block: NASA-TLX (The Blu Day 3)

Start of Block: PANAS (The Blu Day 3)

Timing
First Click
Last Click
Page Submit
Click Count

I-PANAS-SF

Thinking about the virtual experience you just completed, to what extent did you feel **upset**?

- Not at all (1)
- A little (2)
- Moderately (3)
- Quite a bit (4)
- Extremely (5)

Thinking about the virtual experience you just completed, to what extent did you feel **hostile**?

- Not at all (1)
- A little (2)
- Moderately (3)
- Quite a bit (4)
- Extremely (5)

Thinking about the virtual experience you just completed, to what extent did you feel **alert**?

- Not at all (1)
- A little (2)
- Moderately (3)
- Quite a bit (4)
- Extremely (5)

Thinking about the virtual experience you just completed, to what extent did you feel **ashamed**?

- Not at all (1)
- A little (2)
- Moderately (3)
- Quite a bit (4)
- Extremely (5)

Thinking about the virtual experience you just completed, to what extent did you feel **inspired**?

- Not at all (1)
- A little (2)
- Moderately (3)
- Quite a bit (4)
- Extremely (5)

Thinking about the virtual experience you just completed, to what extent did you feel **nervous**?

- Not at all (1)
- A little (2)
- Moderately (3)
- Quite a bit (4)
- Extremely (5)

Thinking about the virtual experience you just completed, to what extent did you feel **determined**?

- Not at all (1)
- A little (2)
- Moderately (3)
- Quite a bit (4)
- Extremely (5)

Thinking about the virtual experience you just completed, to what extent did you feel **attentive**?

- Not at all (1)
- A little (2)
- Moderately (3)
- Quite a bit (4)
- Extremely (5)

Thinking about the virtual experience you just completed, to what extent did you feel **afraid**?

- Not at all (1)
- A little (2)
- Moderately (3)
- Quite a bit (4)
- Extremely (5)

Thinking about the virtual experience you just completed, to what extent did you feel **active**?

- Not at all (1)
- A little (2)
- Moderately (3)
- Quite a bit (4)
- Extremely (5)

During your virtual reality experiences, you were asked to report instances when you experienced sudden transitions from the virtual to the physical environment. Select the appropriate response to indicate the extent that you agree or disagree with the following statements regarding those instances

	Not Applicable: Did not experience any breaks in presence (0)	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
1) After experiencing a break in presence, it took me a long time to get back into the experience	○	○	○	○	○	○
2) After experiencing a break in presence, I had a difficult time concentrating on the virtual environment	○	○	○	○	○	○
3) I felt as though it was easy for me to regain my sense of being in the virtual environment after experiencing a break in presence	○	○	○	○	○	○
4) I felt that the breaks in presence did not detract from my overall experience	○	○	○	○	○	○

5) Breaks in presence were very jarring to the experience	○	○	○	○	○	○
6) It took a lot for my presence to be broken	○	○	○	○	○	○
7) When breaks in presence occurred, I was completely aware of my physical surroundings	○	○	○	○	○	○
8) When breaks in presence occurred, I still maintained some awareness of the virtual environment	○	○	○	○	○	○

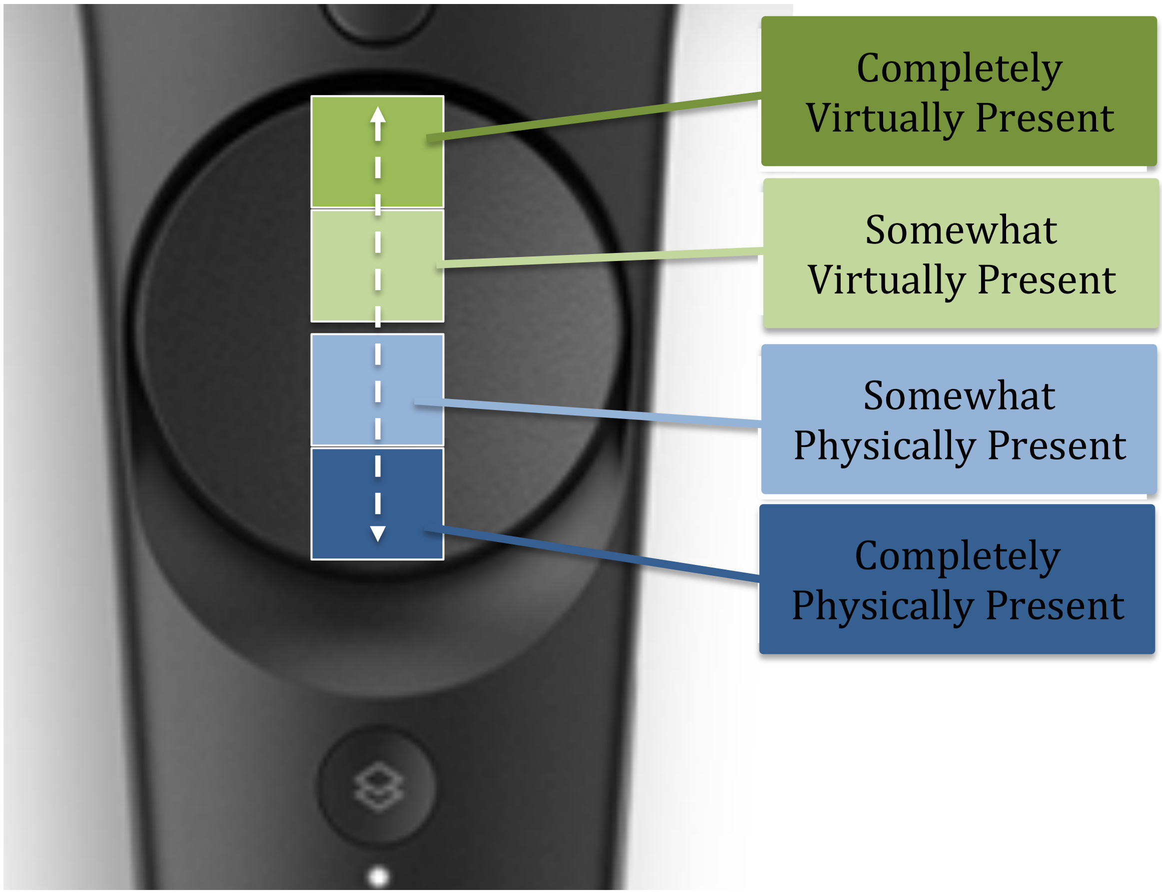
APPENDIX B: RETROSPECTIVE PRESENCE SLIDER INSTRUCTIONS

<u>Video Viewing Instructions</u>

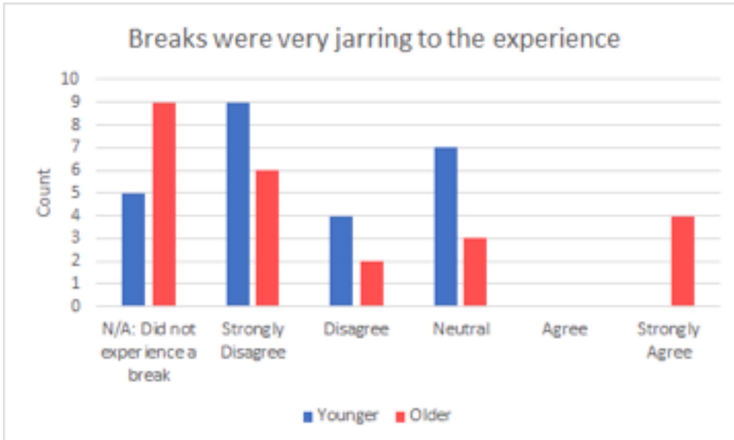
In this next part of the study, you'll be viewing a video of the virtual reality session you just participated in. As you will notice, the video is a recording of exactly what you were seeing during the previous session. As you watch the recording, try to remember where your sense of presence was at *each specific moment* in the experience and slide your finger up and down touchpad to indicate that feeling.

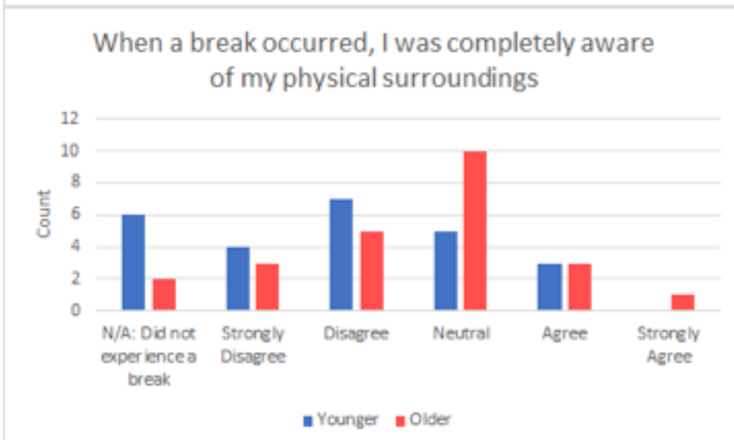
Move or keep your finger at the top of the touchpad to indicate times when you were feeling completely **virtually present** (e.g., you felt like your body was located in the virtual environment, and any of your thoughts and actions you made were in response to things that happened or things you were trying to do in the virtual environment).

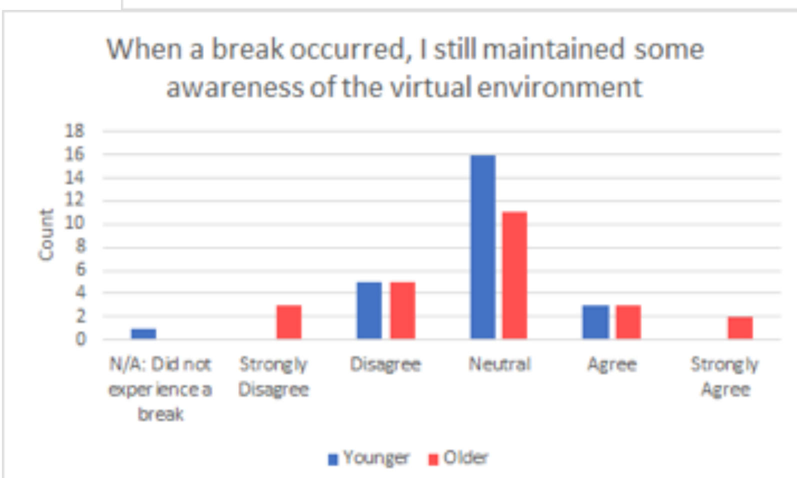
Move or keep your finger at the bottom of the touchpad to indicate times when you were feeling completely **physically present** (you felt very aware of your body being located in this room, and your thoughts and actions were *not* related to the virtual environment).

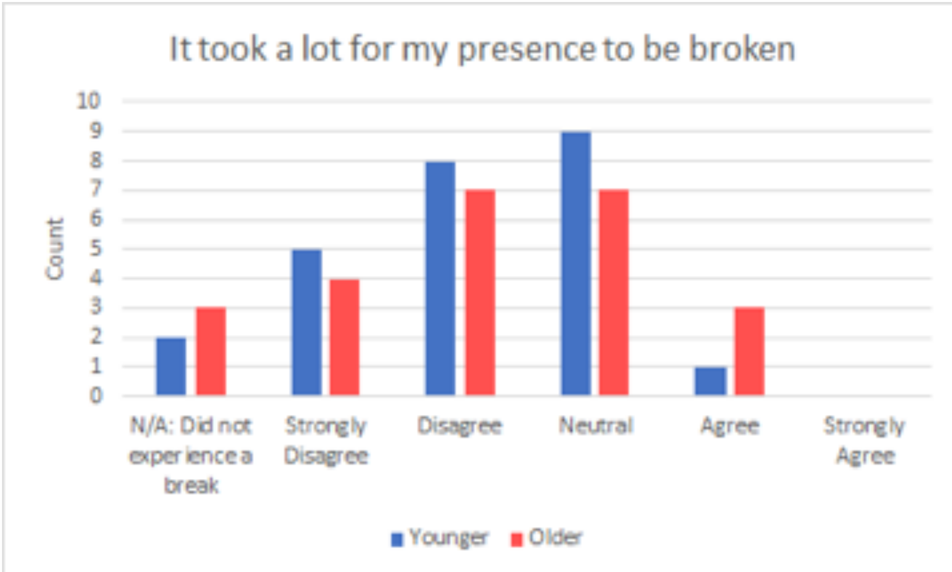

Completely
Virtually Present
Somewhat
Virtually Present
Somewhat
Physically Present
Completely
Physically Present

APPENDIX C: BREAK SUSCEPTIBILITY/RECOVERY RESPONSES








It took a lot for my presence to be broken
Count
10
9
8
7
6
5
4
3
2
1
0
N/A: Did not experience a break
Strongly Disagree
Disagree
Neutral
Agree
Strongly Agree
Younger
Older

APPENDIX D: SEMI-STRUCTURED INTERVIEW

Interview Script:
During your last VR session, I paused the experience twice on purpose, which is when the blue environment surrounded your vision.
What did you see the first time that happened?

- Did you find it to be intrusive to your experience?
- When it occurred, was your ‘sense of being’ stronger in the physical environment or the virtual environment?
- How difficult or easy did you find it to regain your ‘sense of being’ after it happened?

What did you see second time it happened?

- Did you find it to be intrusive to your experience?
- When it occurred, was your ‘sense of being’ stronger in the physical environment or the virtual environment?
- How difficult or easy did you find it to regain your ‘sense of being’ after it happened?

Now let’s talk about your experience as a whole over the course of the three days.

- Many of the questionnaires you completed asked you about your sense of presence in the virtual environment. If you were to describe “presence in virtual reality” to a friend, what would you say?
- Were there any parts of the experience that made you feel more virtually present?
  - If yes – what were they?
- We also discussed transitions to the real, or instances when your sense of presence was broken, such that you became more aware of the physical environment (meaning the room where we are now). Were there any parts of the experience that made you feel less present (broke your presence)?
  - If yes – what were they?
- You were asked to say the word “now” when you experienced these breaks in presence. Did you find it difficult to remember to do this?
  - If yes – why?
- Do you feel that there were any times when you forgot to say “now” even though you experienced a break in presence?
- On average over the course of your VR experiences, how long would you say it took you each time you put on the headset (minutes or seconds) to first feel a ‘sense of presence’ in the virtual environment?
- Over the course of the study when you were in VR, could you give me an estimate of the % of the time you felt virtually present and physically present?
- If this system were offered to you for free, would you like to have it for your home?
- Do you have any final comments about the system or your experience?

APPENDIX E: DINER DUO TUTORIAL PACKET

Diner Duo Training Packet

The next virtual reality scenario simulates the experience of a burger/sandwich chef at a diner. The primary tasks are:

1) Viewing sandwich orders you need to complete
2) Preparing ingredients for those orders
3) Making the sandwich (i.e., putting the ingredients on a bun in the correct order) and placing completed order on the counter

Using the controllers

This is the trigger. Press and hold this using your index finger to pick up items. Release it to drop the item. You will know an item is available to be picked up when it glows a light blue color. This is the main button you'll be using.

Not selectable yet

Selectable

This is the clickable touchpad. Click this button using your thumb to dispense ketchup and mustard from their bottles. You will not need to use this button for anything else.

1) Viewing Sandwich Orders

The sandwich orders will appear in front of you in the speech bubbles. They will remain on the screen until they are completed.

2) Preparing ingredients for the sandwich orders

Some sandwich ingredients require preparation before you can put them on the sandwich:

- **Hamburgers** need to be cooked on the grill.
- **Mushrooms** need to be cut once with the knife to remove the stump, and then be cooked on the grill
- **Fish** need to be cut twice with the knife (once on either end), and then cooked on the grill.
- **Pickle slices** need to be cut off of the full pickle, but do not need to be cooked.
- **Ketchup and mustard** need to be dispensed from their bottles directly onto the sandwich.
- **Cheese** can go directly on the sandwich with no preparation required.

Plates/Buns

All sandwiches need to be assembled on a plate, which can be found toward the left-hand side of your workstation. All sandwiches also require buns, which can be found underneath the front counter of your workstation. The bottom buns are on the left. The top buns are on the right. Before you start preparing any of the other ingredients, it is a good idea to put a plate on the front counter and put a bottom bun on the plate.

Knife

Some of the sandwich ingredients need to be cut with a knife before you can put them on the sandwich. To use the knife, grab it by pressing and holding the trigger and then swiping the blade through the item you're cutting (as you would in real life).

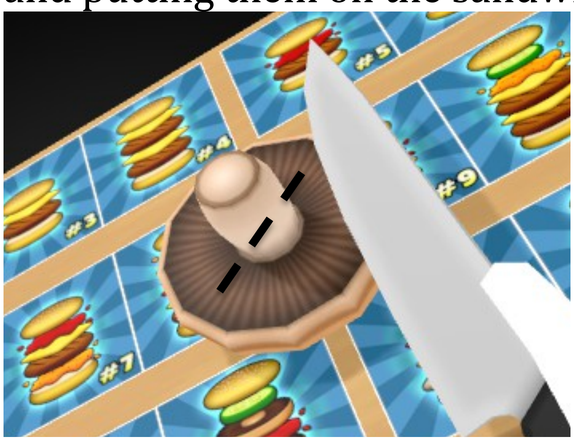
Hamburgers
Hamburger patties can be found on the left-hand side of your workstation. They need to be cooked before you can put them on the sandwich. To cook one, grab it using the trigger and place it on the grill-top which is also on the left-hand side of your workstation (the black surface in the picture below)

When viewing orders, hamburgers look like this:

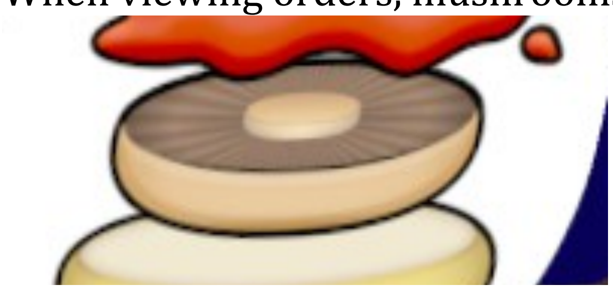
You will be able to tell that the burger is ready once the color changes from pink (left burger) to brown (middle burger) and because you will hear a “ding” sound. Do not let it stay on the grill too long though because if it burns (turns black; right burger) the server will not take it.

Mushrooms
Mushrooms can be found on the left-hand side of your workstation on a shelf above the grill.

Mushrooms need to have the stump cut off before cooking them and putting them on the sandwich



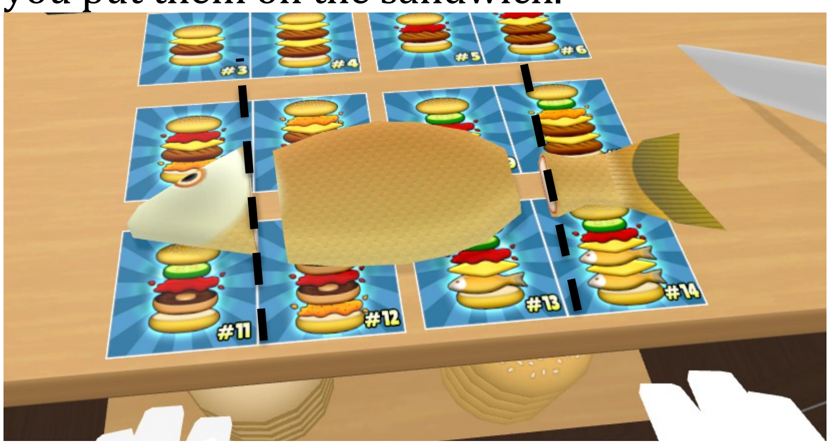
When viewing orders, mushrooms look like this



When the mushroom is ready, it will turn a darker brown color and you will hear a “ding” noise. Mushrooms can also be overcooked. The image below shows a raw (left), properly cooked (middle), and burnt (right) mushroom.

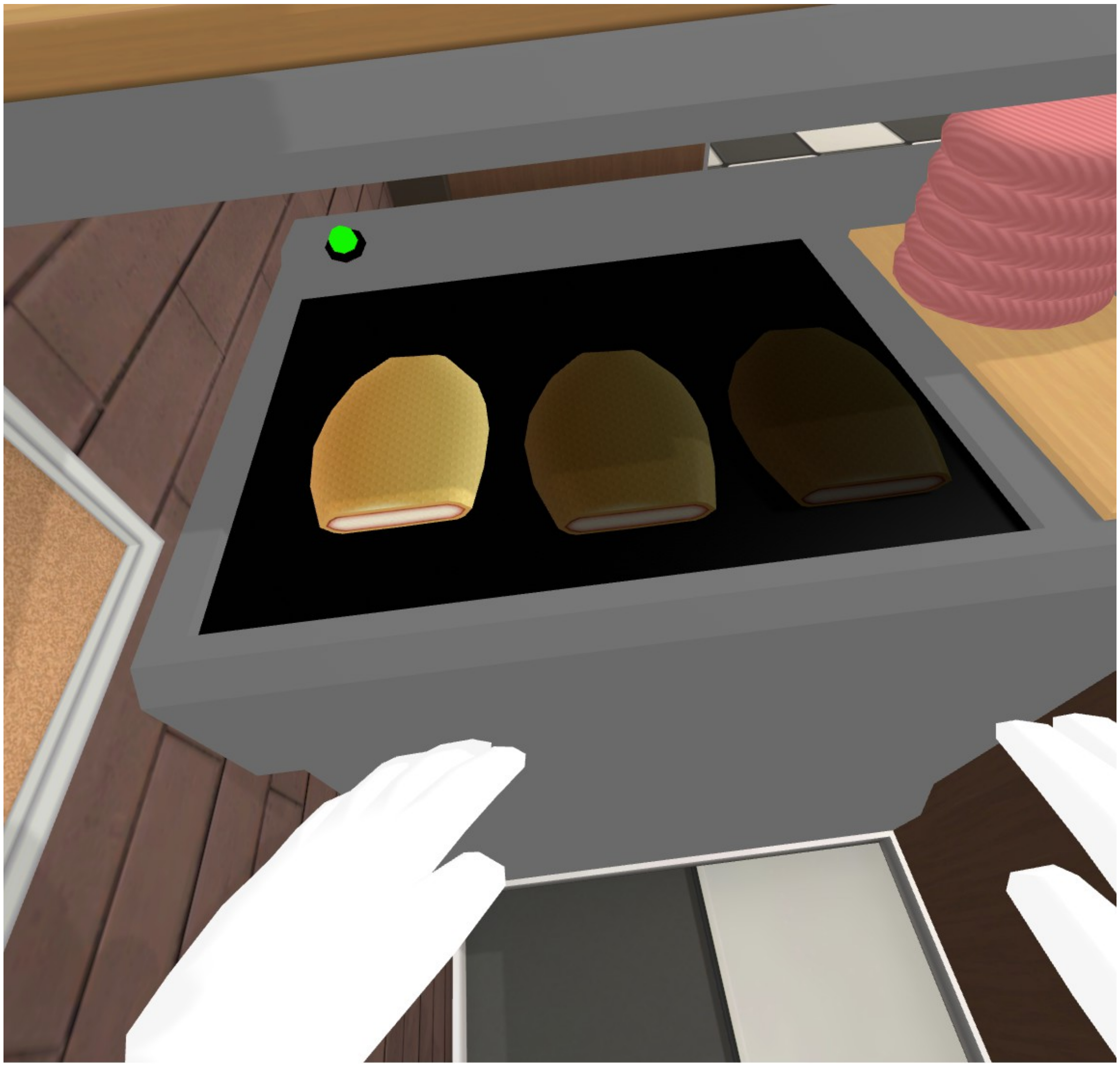
Fish
Fish can be found on the right-hand side of your workstation on a shelf above the pickle and knife.

Fish need to be cut on both ends with the knife and cooked before you put them on the sandwich.



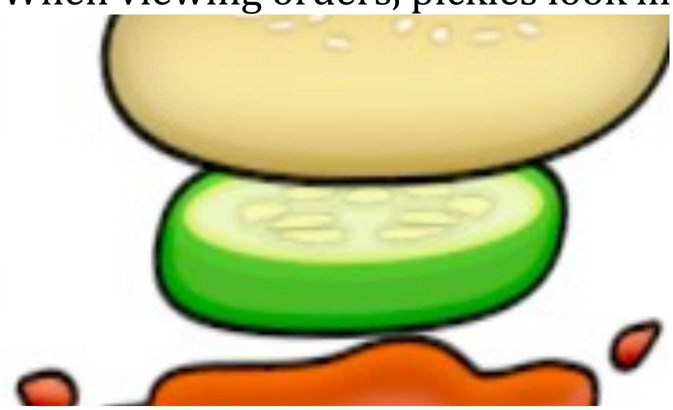
When viewing orders, fish look like this:

When the fish is ready, it will turn a brown color and you will hear a “ding” noise. Fish can also be overcooked. The image below shows a raw (left), properly cooked (middle), and burnt (right) fish.



NOTE: Do not let your food go bad!
Hamburgers, mushrooms, and fish can go bad after you cook them if you wait too long to give the sandwich to the server. If they go bad, the server will not take the sandwich from you and you will need to remove the bad ingredient(s) and redo it. You will know ingredients have gone bad because they will turn green and emit a green smoke (see below). Because your cooked items go bad if they sit out for too long, it is a good idea to cut your ingredients before you cook them.

Pickle
The pickle can be found on the right-hand countertop of your workstation. Pickle slices need to be cut off the full pickle before being placed on the sandwich


When viewing orders, pickles look like this:


Cheese
Cheese can be found toward the right-hand side of your workstation. Cheese is ready-to-go, meaning you do not need to do any preparation, you can just grab it and place it on the sandwich.

When viewing orders, cheese looks like this:

Ketchup/Mustard

Ketchup and mustard can be found toward the right-hand side of your workstation

When viewing orders, ketchup (left) and mustard (right) look like this:

Put them on the sandwich by grabbing them (using the trigger on the controller with your index finger) and dispensing them onto the sandwich (by clicking the touchpad on the controller with your thumb)

3) Making the sandwich & placing it on the counter

The sandwich needs to be assembled in the exact order shown in the speech bubbles. You will also need to put the sandwich on a plate or the server will not take it. When you have assembled the sandwich correctly, grab the plate it is on and put it on the black part of the countertop in front of the server. If it is correct, the server will grab it and the speech bubble will go away. If it is not correct, the server will leave it on the countertop and the speech bubble will remain. If this happens, it means either your ingredients are not in the correct order (or you are missing something) or that one of your ingredients is burnt (turned black) or gone bad (turned green). You will need to fix or make a new sandwich to continue.

Note: Do not try to pick up items that fall on the floor!
If you happen to drop your knife, ketchup/mustard bottles, or the uncut pickle on the floor, do not worry. They will reappear in their original location on the countertop after a few seconds. Similarly, if you drop any food items on the floor, do not try to pick them back up, just redo the item.

APPENDIX F: PRESENCE CORRELATION TABLE

Younger adults

Correlations																		
Group			Cube_Comparison	UFOV_Divided	UFOV_Focused	Stroop_RT_Incon_Con_Diff	Flanker_RT_Incon_Con_Diff	TMT_Secs_Shifting	TMT_Secs_Flexibility	Attention Allocation	Spatial Situation Model	Self-Location	Possible Actions	Cognitive Involvement	Suspension of Disbelief	Breaks in Presence	Slider % Virtual	Slider Mean
Younger Adult		Correlation Coefficient			-0.145	-0.078	0.02	-0.085	-0.108	0.386	0.288	0.184	0.113	-0.036	0.148	-0.068	0.282	0.189
		Sig. (2-tailed)			0.491	0.71	0.924	0.687	0.609	0.057	0.163	0.378	0.592	0.865	0.479	0.747	0.172	0.365
	Cube_Comparison	N			25	25	25	25	25	25	25	25	25	25	25	25	25	25
	UFOV_Divided	Correlation Coefficient			0.251	-0.06	.405*	0.168	-0.067	-0.123	-0.369	-0.268	-0.099	-0.058	-0.072	0.106	-0.289	-0.275
		Sig. (2-tailed)			0.226	0.775	0.045	0.423	0.751	0.559	0.07	0.195	0.636	0.784	0.731	0.615	0.161	0.183
		N			25	25	25	25	25	25	25	25	25	25	25	25	25	25
	UFOV_Focused	Correlation Coefficient			1	0.266	-0.052	0.082	0.09	-0.011	0.21	0.022	0.088	0.248	-0.097	0.028	0.192	0.094
		Sig. (2-tailed)			.	0.198	0.804	0.696	0.667	0.957	0.313	0.917	0.675	0.233	0.644	0.895	0.358	0.654
		N			25	25	25	25	25	25	25	25	25	25	25	25	25	25
	Stroop_RT_Incon_Con_Diff	Correlation Coefficient			0.266	1	0.209	0.077	0.024	-0.108	0.145	-0.027	-0.001	0.191	0.109	0.077	-0.084	-0.139
		Sig. (2-tailed)			0.198	.	0.315	0.715	0.91	0.606	0.488	0.899	0.996	0.36	0.602	0.715	0.69	0.509
		N			25	25	25	25	25	25	25	25	25	25	25	25	25	25
	Flanker_RT_Incon_Con_Diff	Correlation Coefficient			-0.052	0.209	1	0.05	-0.299	0.024	-0.192	-0.328	-0.04	-0.116	0.052	0.226	-0.232	-0.326
		Sig. (2-tailed)			0.804	0.315	.	0.812	0.146	0.908	0.357	0.109	0.848	0.581	0.805	0.278	0.265	0.112
		N			25	25	25	25	25	25	25	25	25	25	25	25	25	25
	TMT_Secs_Shifting	Correlation Coefficient			0.082	0.077	0.05	1	.680**	0.296	-0.045	0.079	0.04	0.089	0.32	0.004	-0.108	-0.089
		Sig. (2-tailed)			0.696	0.715	0.812	.	0	0.151	0.831	0.708	0.85	0.673	0.118	0.985	0.608	0.671
		N			25	25	25	25	25	25	25	25	25	25	25	25	25	25
	TMT_Secs_Flexibility	Correlation Coefficient			0.09	0.024	-0.299	.680**	1	0.016	-0.185	0.017	-0.192	-0.173	0.251	0	-0.108	0.004
		Sig. (2-tailed)			0.667	0.91	0.146	0	.	0.94	0.377	0.934	0.358	0.408	0.227	0.999	0.608	0.985
		N			25	25	25	25	25	25	25	25	25	25	25	25	25	25
	Attention Allocation	Correlation Coefficient			-0.011	-0.108	0.024	0.296	0.016	1	.486*	.687**	.682**	.438*	-0.002	-0.117	0.202	0.178
		Sig. (2-tailed)			0.957	0.606	0.908	0.151	0.94	.	0.014	0	0	0.029	0.994	0.577	0.334	0.394
		N			25	25	25	25	25	25	25	25	25	25	25	25	25	25
	Spatial Situation Model	Correlation Coefficient			0.21	0.145	-0.192	-0.045	-0.185	.486*	1	.714**	.669**	.614**	-0.04	0.006	.491*	.449*
		Sig. (2-tailed)			0.313	0.488	0.357	0.831	0.377	0.014	.	0	0	0.001	0.851	0.978	0.013	0.024
		N			25	25	25	25	25	25	25	25	25	25	25	25	25	25
	Self-Location	Correlation Coefficient			0.022	-0.027	-0.328	0.079	0.017	.687**	.714**	1	.722**	.489*	0.088	-0.018	.430*	.520**
		Sig. (2-tailed)			0.917	0.899	0.109	0.708	0.934	0	0	.	0	0.013	0.677	0.93	0.032	0.008
		N			25	25	25	25	25	25	25	25	25	25	25	25	25	25
	Possible Actions	Correlation Coefficient			0.088	-0.001	-0.04	0.04	-0.192	.682**	.669**	.722**	1	.802**	-0.212	0.183	0.325	0.323
		Sig. (2-tailed)			0.675	0.996	0.848	0.85	0.358	0	0	0	.	0	0.31	0.382	0.113	0.116
		N			25	25	25	25	25	25	25	25	25	25	25	25	25	25
	Cognitive Involvement	Correlation Coefficient			0.248	0.191	-0.116	0.089	-0.173	.438*	.614**	.489*	.802**	1	-.453*	0.068	0.155	0.105
		Sig. (2-tailed)			0.233	0.36	0.581	0.673	0.408	0.029	0.001	0.013	0	.	0.023	0.745	0.458	0.617
		N			25	25	25	25	25	25	25	25	25	25	25	25	25	25
	Suspension of Disbelief	Correlation Coefficient			-0.079	0.231	-0.068	-0.052	-0.147	0.026	0.095	0.159	0.05	0.307	-0.308	0.048	-0.083	-0.046
		Sig. (2-tailed)			0.707	0.267	0.748	0.806	0.484	0.902	0.651	0.448	0.813	0.135	0.134	0.82	0.695	0.827
		N			25	25	25	25	25	25	25	25	25	25	25	25	25	25
	Breaks In Presence	Correlation Coefficient			0.028	0.077	0.226	0.004	0	-0.117	0.006	-0.018	0.183	0.068	-0.078	1	-0.153	0.018
		Sig. (2-tailed)			0.895	0.715	0.278	0.985	0.999	0.577	0.978	0.93	0.382	0.745	0.711	.	0.464	0.932
		N			25	25	25	25	25	25	25	25	25	25	25	25	25	25
	Slider % Virtual	Correlation Coefficient			0.192	-0.084	-0.232	-0.108	-0.108	0.202	.491*	.430*	0.325	0.155	0.117	-0.153	1	.934**
		Sig. (2-tailed)			0.358	0.69	0.265	0.608	0.608	0.334	0.013	0.032	0.113	0.458	0.579	0.464	.	0
		N			25	25	25	25	25	25	25	25	25	25	25	25	25	25
	Slider Mean	Correlation Coefficient			0.094	-0.139	-0.326	-0.089	0.004	0.178	.449*	.520**	0.323	0.105	0.173	0.018	.934**	1
		Sig. (2-tailed)			0.654	0.509	0.112	0.671	0.985	0.394	0.024	0.008	0.116	0.617	0.408	0.932	0	.
		N			25	25	25	25	25	25	25	25	25	25	25	25	25	25

Older adults

Group			Cube_Comparison	UFOV_Divided	UFOV_Focused	Stroop_RT_Incon_Con_Diff	Flanker_RT_Incon_Con_Diff	TMT_Secs_Shifting	TMT_Secs_Flexibility	Attention Allocation	Spatial Situation Model	Self-Location	Possible Actions	Cognitive Involvement	Suspension of Disbelief	Breaks in Presence	Slider % Virtual	Slider Mean
Older Adults	Cube_Comparison	Correlation Co	1	-0.312	-0.245	-0.306	-0.091	-0.309	-.473*	-0.272	0.349	0.08	0.296	0.114	0.351	-0.313	0.39	.406*
		Sig. (2-tailed)		0.129	0.238	0.147	0.679	0.133	0.017	0.189	0.087	0.704	0.15	0.586	0.085	0.128	0.06	0.049
		N		25	25	24	23	25	25	25	25	25	25	25	25	25	24	24
	UFOV_Divided	Correlation Coefficient		1	.808**	.420*	-0.053	0.259	0.37	0.1	-0.396	-0.079	-0.294	-0.096	0.003	-0.097	-0.153	-0.266
		Sig. (2-tailed)		.	0	0.041	0.81	0.212	0.069	0.634	0.05	0.708	0.154	0.647	0.991	0.643	0.474	0.209
		N			25	24	23	25	25	25	25	25	25	25	25	25	24	24
	UFOV_Focused	Correlation Coefficient			1	0.211	-0.153	.398*	0.365	-0.048	-.511**	-0.287	-.453*	-0.215	-0.028	-0.111	-0.317	-0.249
		Sig. (2-tailed)			.	0.323	0.486	0.049	0.072	0.82	0.009	0.165	0.023	0.302	0.893	0.597	0.131	0.241
		N			25	24	23	25	25	25	25	25	25	25	25	25	24	24
	Stroop_RT_Incon_Con_Diff	Correlation Coefficient			0.211	1	-0.313	0.091	0.117	0.058	-.491*	-0.031	-.425*	0.023	0.033	0.037	-0.307	-0.226
		Sig. (2-tailed)			0.323	.	0.146	0.671	0.588	0.789	0.015	0.884	0.038	0.916	0.878	0.864	0.144	0.288
		N			24	24	23	24	24	24	24	24	24	24	24	24	24	24
	Flanker_RT_Incon_Con_Diff	Correlation Coefficient			-0.153	-0.313	1	-0.241	-0.145	0.07	0.139	-0.182	-0.006	0.089	-0.237	-0.324	0.239	-0.064
		Sig. (2-tailed)			0.486	0.146	.	0.268	0.508	0.75	0.526	0.405	0.977	0.687	0.276	0.132	0.271	0.771
		N			23	23	23	23	23	23	23	23	23	23	23	23	23	23
	TMT_Secs_Shifting	Correlation Coefficient			.398*	0.091	-0.241	1	.792**	-0.237	-0.199	-0.044	-0.068	-0.125	-0.166	0.229	-0.25	-0.27
		Sig. (2-tailed)			0.049	0.671	0.268	.	0	0.255	0.341	0.834	0.747	0.553	0.429	0.27	0.239	0.201
		N			25	24	23	25	25	25	25	25	25	25	25	25	24	24
	TMT_Secs_Flexibility	Correlation Coefficient			0.365	0.117	-0.145	.792**	1	0.133	-0.128	0.148	-0.016	-0.056	-0.127	0.145	-0.343	-.463*
		Sig. (2-tailed)			0.072	0.588	0.508	0	.	0.527	0.543	0.48	0.939	0.791	0.544	0.49	0.101	0.023
		N			25	24	23	25	25	25	25	25	25	25	25	25	24	24
	Attention Allocation	Correlation Coefficient			-0.048	0.058	0.07	-0.237	0.133	1	.411*	.589**	0.329	.533**	0.025	-0.049	-0.179	-0.235
		Sig. (2-tailed)			0.82	0.789	0.75	0.255	0.527	.	0.041	0.002	0.108	0.006	0.906	0.815	0.402	0.269
		N			25	24	23	25	25	25	25	25	25	25	25	25	24	24
	Spatial Situation Model	Correlation Coefficient			-.511**	-.491*	0.139	-0.199	-0.128	.411*	1	.593**	.841**	.453*	0.202	-0.089	0.293	0.138
		Sig. (2-tailed)			0.009	0.015	0.526	0.341	0.543	0.041	.	0.002	0	0.023	0.334	0.674	0.165	0.521
		N			25	24	23	25	25	25	25	25	25	25	25	25	24	24
	Self-Location	Correlation Coefficient			-0.287	-0.031	-0.182	-0.044	0.148	.589**	.593**	1	.673**	.471*	0.086	0.042	0.075	-0.017
		Sig. (2-tailed)			0.165	0.884	0.405	0.834	0.48	0.002	0.002	.	0	0.018	0.683	0.841	0.726	0.939
		N			25	24	23	25	25	25	25	25	25	25	25	25	24	24
	Possible Actions	Correlation Coefficient			-.453*	-.425*	-0.006	-0.068	-0.016	0.329	.841**	.673**	1	0.345	0.257	-0.144	.448*	0.251
		Sig. (2-tailed)			0.023	0.038	0.977	0.747	0.939	0.108	0	0	.	0.092	0.216	0.493	0.028	0.237
		N			25	24	23	25	25	25	25	25	25	25	25	25	24	24
	Cognitive Involvement	Correlation Coefficient			-0.215	0.023	0.089	-0.125	-0.056	.533**	.453*	.471*	0.345	1	-0.059	-0.003	-0.019	-0.092
		Sig. (2-tailed)			0.302	0.916	0.687	0.553	0.791	0.006	0.023	0.018	0.092	.	0.779	0.988	0.93	0.668
		N			25	24	23	25	25	25	25	25	25	25	25	25	24	24
	Suspension of Disbelief	Correlation Coefficient			-0.028	0.033	-0.237	-0.166	-0.127	0.025	0.202	0.086	0.257	-0.059	1	-0.232	0.189	0.352
		Sig. (2-tailed)			0.893	0.878	0.276	0.429	0.544	0.906	0.334	0.683	0.216	0.779	.	0.264	0.376	0.091
		N			25	24	23	25	25	25	25	25	25	25	25	25	24	24
	Breaks In Presence	Correlation Coefficient			-0.111	0.037	-0.324	0.229	0.145	-0.049	-0.089	0.042	-0.144	-0.003	-0.232	1	-.449*	-0.276
		Sig. (2-tailed)			0.597	0.864	0.132	0.27	0.49	0.815	0.674	0.841	0.493	0.988	0.264	.	0.028	0.191
		N			25	24	23	25	25	25	25	25	25	25	25	25	24	24
	Slider % Virtual	Correlation Coefficient			-0.317	-0.307	0.239	-0.25	-0.343	-0.179	0.293	0.075	.448*	-0.019	0.189	-.449*	1	.824**
		Sig. (2-tailed)			0.131	0.144	0.271	0.239	0.101	0.402	0.165	0.726	0.028	0.93	0.376	0.028	.	0
		N			24	24	23	24	24	24	24	24	24	24	24	24	24	24
	Slider Mean	Correlation Coefficient			-0.249	-0.226	-0.064	-0.27	-.463*	-0.235	0.138	-0.017	0.251	-0.092	0.352	-0.276	.824**	1
		Sig. (2-tailed)			0.241	0.288	0.771	0.201	0.023	0.269	0.521	0.939	0.237	0.668	0.091	0.191	0	.
		N			24	24	23	24	24	24	24	24	24	24	24	24	24	24

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